

Control ENGINEERING

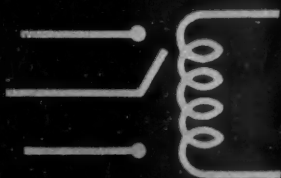
INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

A MCGRAW-HILL PUBLICATION

PRICE 50 CENTS

JANUARY 1957

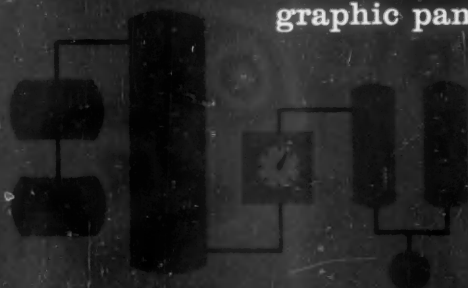
electromechanical



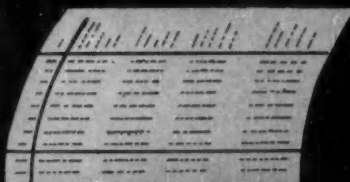
solid-state logic



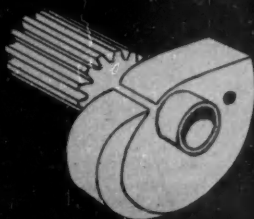
graphic panels



automatic data logging



cams and templates



numerical control



1957

a year for
CONTROL in transition

now FOR DC OR RESISTANCE INPUT

MODEL 200-A uses an input of 10,000 ohm resistance potentiometers as an input transducer providing 10 to 1 scale expansion and origin positioning. Available standard digital input accessories are essentially inputs of this type. Any resistance potentiometer will provide an analog input for this configuration.

MODEL 200-B, used for D.C. signal input, has full scale sensitivities of 5 millivolts and an input impedance of 1,000 megohms. Utilizing standard reference cells, this model provides drift-free operation. Available external reference voltages may be substituted. A plug connection is provided to facilitate the quick interchangeability of input sections.

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Precision Vernier Dials provide an accurate method for obtaining fine adjustment during operation. Optional point plot or continuous line plotting is a feature of both models. Selection is by front panel manual control. A new, simplified pen of one-piece design—used for point or continuous plotting—eliminates bottles and tubes, permits rapid changing of ink colors. Independent action of the X and Y axis is achieved with Librascope's unique "Floating Gear Train." No cables, tapes or lead screws to cause lost motion, cable stretching or drifting out of alignment. The 120° concave cylindrical plotting surface provides full visibility... is completely illuminated.

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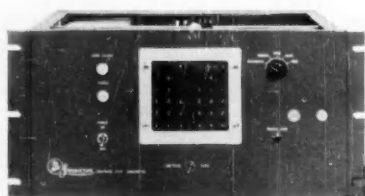
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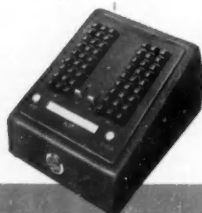
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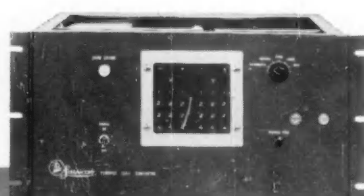
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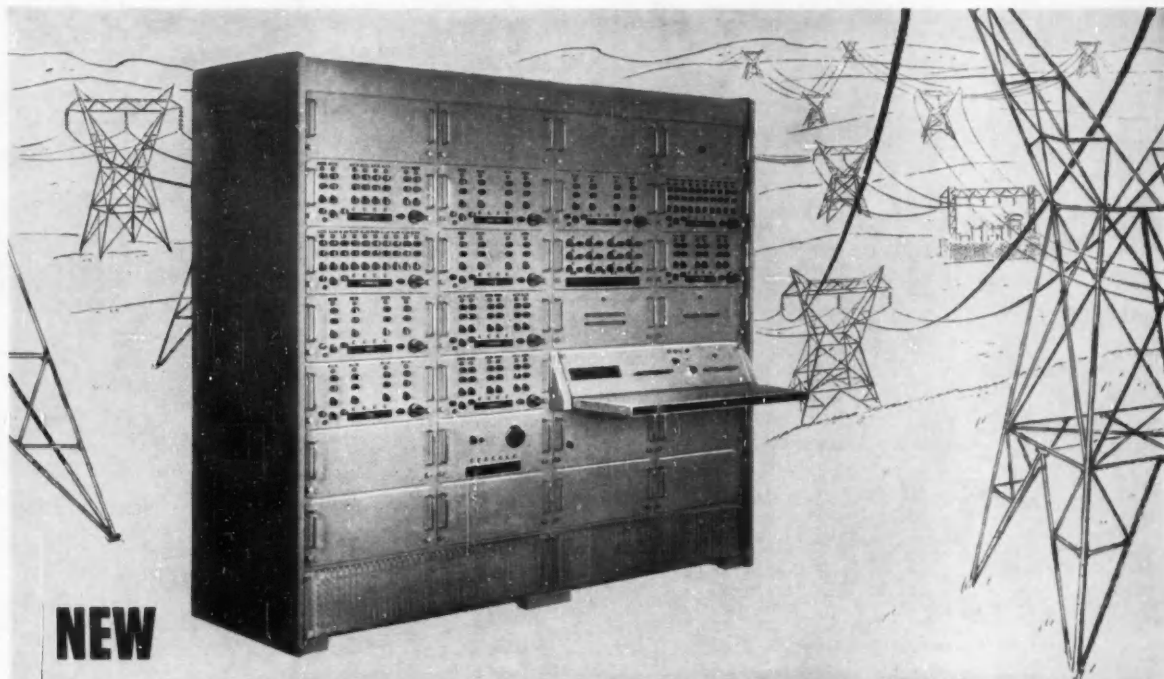
NEW LIBRASCOPE PUNCHED TAPE CONVERTER
Operates from a punched tape reader—Specially designed for Librascope X-Y Plotters—This unit is adaptable to other plotters.



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Matching power plant output to the ever-changing load demands of its customers has always been one of the biggest operational problems of every power company. Hundreds of engineers and mathematicians continually spend thousands of hours poring over past operational data in an effort to calculate the most efficient and economical operating schedule. But even the best mechanical computing methods can only approximate the never-ending day-to-day load variations. So, every day main plants and substations continue to cycle between overload and excess capacity. The result — excessive fuel consumption and higher power costs.

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Now available is a new Goodyear Engineering Report, GER-6969, which describes the operation of the GEDA A-14 Economic Power Dispatch Computer.

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Lapp


Control ENGINEERING

JANUARY 1957
VOLUME 4 NUMBER 1

INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS
Published for engineers and technical management men who are responsible for
the design and application of instrumentation and automatic control systems.

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Control ENGINEERING

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To this month's Digital Series author, Dr. A. S. Householder, goes the honor of being the "compleat" control engineer—one who, we insist, should be one part engineer, one part scientist, and one part reporter. He admirably fills the first two-thirds of the requirements with his writing on the human nervous system and his designs for lead-computing gun sights. And Ed Kompass testifies to his reporting ability: "Sure his article is the longest in our long Digital Series; but it was just too well written . . . I didn't have heart to abridge it."

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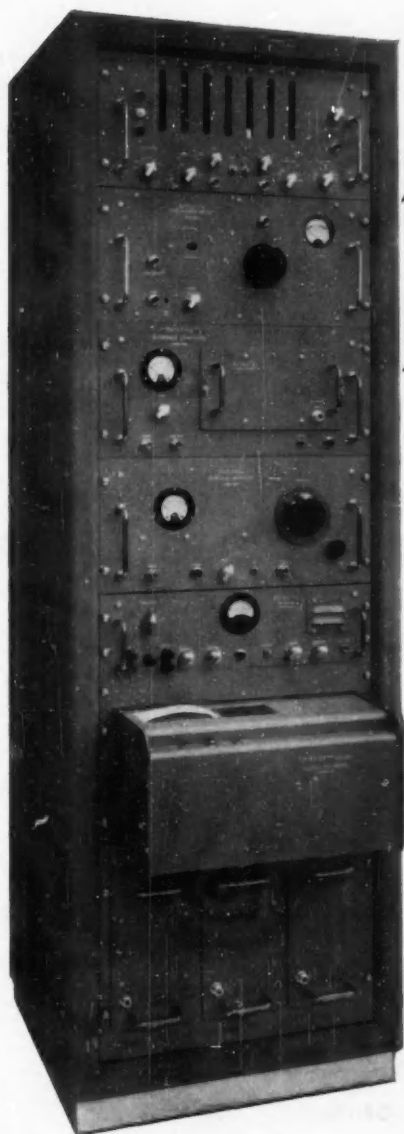
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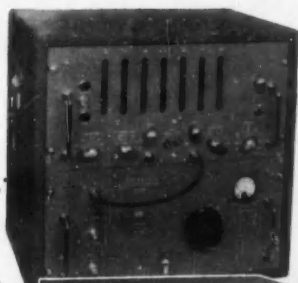
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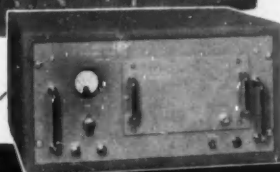




Typical automatic frequency measurement and logging system showing (top to bottom) Model 5571 Frequency Meter, Model 5580 Reference Generator with Model 5581 Plug-in, Model 5585 Selective Amplifier, Model 5590 WWV Receiver, and Model 1452 Digital Recorder.



Model 5571 0-42 mc Frequency Meter; price, \$1,745.00



Model 5580 Reference Generator, with 5581 series plug-ins, extends range to 515 mc. Price, Model 5580, \$300.00; 5581/4 plug-in (42-155 mc) \$150.00; 5581/15 thru 48 (152 to 515 mc in 33 mc bands), \$100.00 each.

The Frequency Meter That Grows With The Job

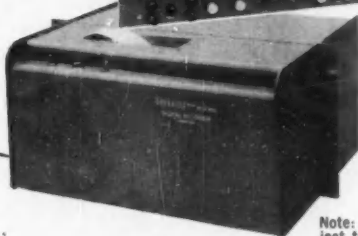
Berkeley Model 5571



Model 5585 Selective Amplifier provides 100 microvolt sensitivity in the 0-42 mc range. Price, \$425.00



Model 5590 WWV receiver permits calibration of 5571 within ± 2 parts in 10^6 , for use as secondary frequency and time standard. Price, \$495.00



Model 1452 Digital Recorder automatically prints readings on standard adding machine tape. Price, (6-digit), \$850.00

Note: All prices f.o.b. factory, subject to change without notice.

FLEXIBILITY...

here's the **one** frequency meter that won't be out-dated as your requirements grow or change. By adding matched accessory units, you can extend its range to 515 mc, add a WWV receiver for calibration within ± 2 parts in 10^6 , or a digital recorder to print measured frequency automatically on standard adding machine tape.

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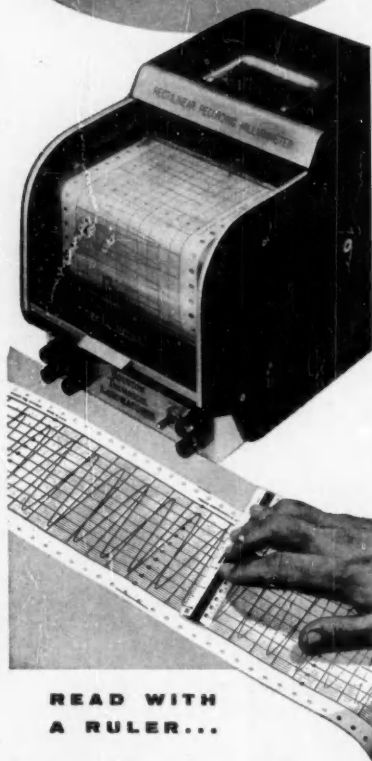
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SHOPTALK

Control in Transition?

Our cover this month may be a wee bit overdramatic. It focuses on three of the most exciting developments in our field and hints that 1957 may well be the year for proving their salt. For effect, Art Director Jack Gordon displays the movement of these new concepts dynamically . . . as movement from the established towards the new. However, we must qualify the drama of our cover design here . . .

Enhance More Than Supplant

One of the fascinating features of our field is that existing technique is never really static: it usually activates and develops—and excels when competing methods appear. Take that classic electron tube—the grid-control rectifier, or thyatron. Jim Burnett's article on page 88 shows how, despite the threat of magnetic amplifying techniques, new uses and new potential have come to this old standby. The same holds for that tried-and-true building block of most control systems—the electromechanical switch. As By Ledgerwood notes in his report on the recent Cincinnati machine tool control conclave (page 20), despite much hullabaloo about dynamic statics, the general conclusion was that "the future system will probably be a combination of both electromechanical and static switching devices".

Augment More Than Obfuscate

Just as tenacious, reports Lloyd Slater, is the visual process control panel as it faces the incoming data logger. Participants at the Philadelphia Symposium (page 21) agree that complete digital control of a process is possible. But, they asked, how will the control information be displayed? It took a representative from a computer maker to suggest that the digits would have to appear on a graphical picture of the process. As Lloyd says in his *Industry's Pulse* (page 59), the data logger will never "completely obfuscate" the analog display. (His Symposium paper said the same thing.)

Trial By Feedback

The year 1957 then, is when digital and static control goes on trial. Our job will be to report the pioneer user experiences, feedback which may throttle down the wilder claims carried through from '56.

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Five compact models, up to 100 amperes, AC, up to 12 taps. All-ceramic and metal construction. Silver-to-silver contacts, with self-cleaning rotor contact.

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FEEDBACK

Hot-collared professional sounds off

TO THE EDITOR—

OK—I waited for your complete series. Now I ask Do you REALLY believe that there is a shortage of engineers? I realize that shortage talk is favored by employers and educators, but how can anyone:

1. look at the great rooms full of "engineers" sitting at long rows of desks and say that there is a shortage? shortage of what? detailers? maybe; but not of engineering graduates.
2. claim there is a shortage after counting the engineers who have left the profession to earn a living at more lucrative employment, or left industry for their own business or practice?

If we accept the newspapers' figures of truck drivers' pay and the employment agencies' figures of engineers' pay, we find more than half of the engineering graduates receiving less per week than truck drivers after 10 years' experience.

Granted, employers would like to see a line of men at the employment office and educators would like to expand their departments. But until we make use of the engineers we now have, what are we going to do with more? (I know—make the rows of desks longer.)

THE LAW OF SUPPLY AND DEMAND HAS NOT BEEN REPEALED! When more engineers are needed, the wages will rise enough to
(Continued on page 11)

PROBLEM FORUM . . .

. . . presents a prize-winning answer from a Blue Nose to Los Angeles County's call for an automatic ballot-tallying system. Posed in the November '55 Problem Forum were these general system requirements:

1. Keep a running tally of votes for each candidate.
2. Allow candidates' names to appear in different order on each ballot.
3. Permit voting for one candidate or any number up to all but one (occurs in electing a city council).
4. Reject spoiled ballots, i.e., ones upon which selections have been made of the wrong number of candidates.

Continue to send in your problems and answers. Modest rewards await those published. Now, into the answer offered . . .

TO THE EDITOR—

Figure 1 shows a typical ballot which has, in addition to the candidates' names, holes which code the

name. A voter has cast for candidate Brown by placing a ballot in the device shown in Figure 2 and pushing
(Continued on page 10)

Name	Code	Spore	Vote
Jones	□		
Smith	□□		
Black	□□□		
Brown	□□□□		● "Vote hole"
White	□□□□□		
Doe	□□□□□□		
Cook	□□□□□□□		
	□ "Orientation," "Read" hole		

FIG. 1. Ballot card.

Not to scale

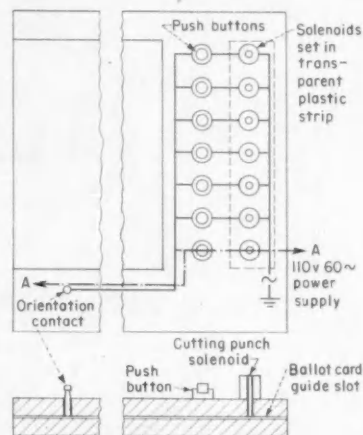


FIG. 2. Ballot puncher.

Section A-A

Not to scale

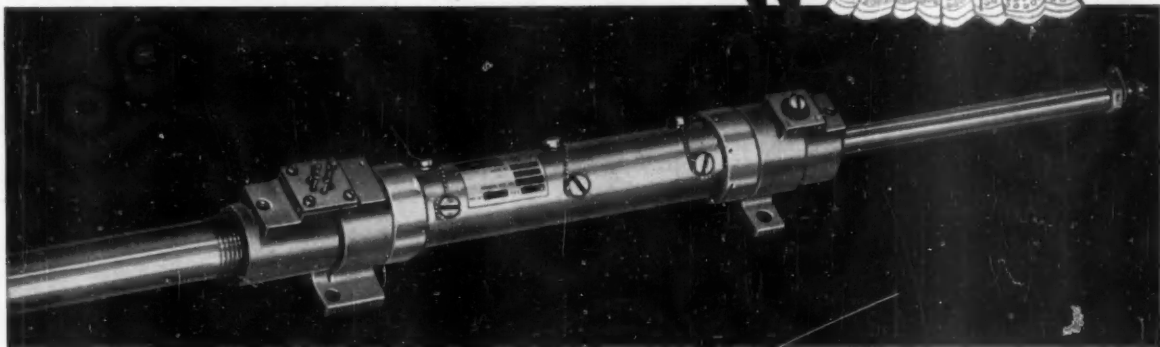
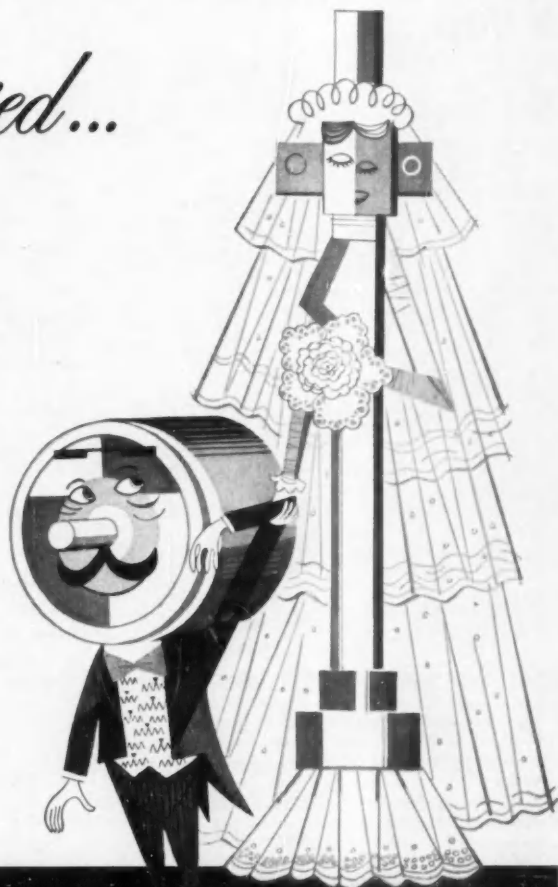
Just Married...

In an unusual setting in the laboratories of G. M. Giannini & Co., Inc., Miss Hydraulic Actuator and Mr. Precision Potentiometer recently were united at ceremonies attended by leading engineers and scientists. Solicitous friends have long awaited this happy union...the couple, known to their intimates as Ac-pot, soon will reside in the most advanced control systems being developed.

THE FACTS ARE... Giannini engineers are the first to incorporate the vital potentiometer elements inside the actuator case, saving space and, at the same time improving performance.

The hydraulic fluid cleans and lubricates the windings, reducing noise and increasing the useful life of the potentiometer. Heat dissipation is improved and performance is not affected by environmental hazards such as humidity, fungus, dust and salt spray.

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JANUARY 1957

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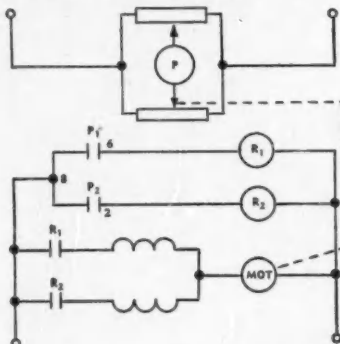


ultra-sensitive relays

HELPFUL DATA FOR YOUR CIRCUITRY IDEA FILE...

(No. 2 in a series by Barber-Colman Company)

The circuit drawing below indicates just one of the hundreds of ways many manufacturers are utilizing Barber-Colman Micropositioner ultra-sensitive relays to solve complex control problems. Could this be the answer to some of yours, too?



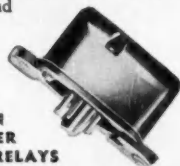
SERVOMECHANISMS APPLICATIONS

Many remote positioning applications can be solved by utilizing the Barber-Colman Micropositioner ultra-sensitive relay either as a null detector or a differential relay.

In the circuit shown above, movement of the transmitting potentiometer introduces an error signal in Micropositioner coil P, which in turn energizes the positioning motor until balance is restored. Secondary relays R_1 and R_2 operated by the Micropositioner handle larger loads. This circuit can also be applied to synchronization... or the Micropositioner can be utilized in the output of an electronic servo control.

Among the many applications for this simplified servo control relay are positioning of antenna rotators and tuning condensers... aerial camera mounts... valves... test cell apparatus.

If your projects involve servomechanisms, why not make a test with a Micropositioner designed for circuits similar to that shown above? Write for technical bulletins F7279 and F3961-5.



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Various types...plug-in, solder-lug, screw terminal, hermetically sealed. Operate on input powers of 50 to 1,000 microwatts for use in photoelectric circuits, resistance bridge circuits, and electronic plate circuits. Send for data.

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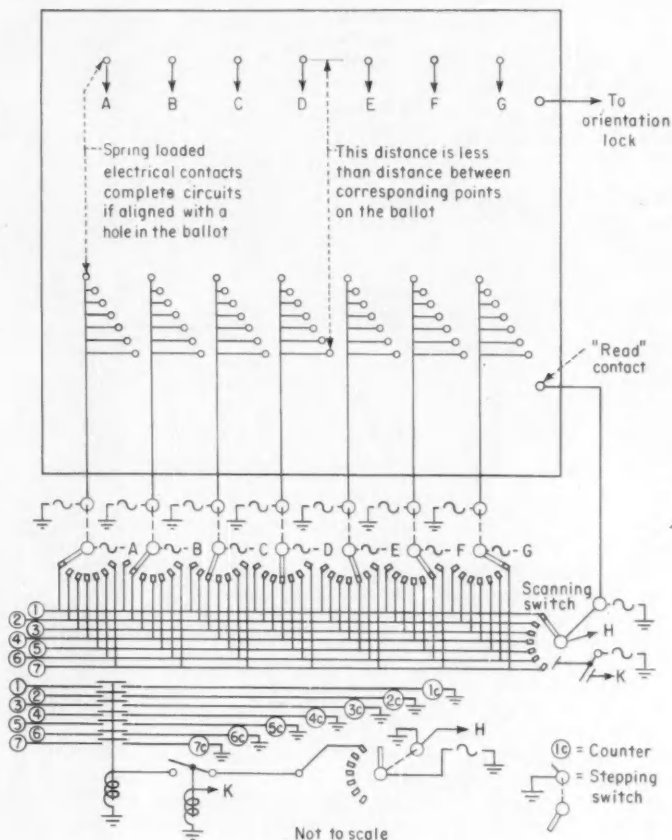


FIG. 3. Schematic of Ballot Tallying System.

a button opposite Brown's name. Pushing the button operated a solenoid, which cut the "vote" hole.

The ballot tallier shown in Figure 3 then follows this sequence:

(a) Introduced into the slot at the top, the ballot rests on a platform like a slice of bread in an automatic toaster. With the orientation slot in the correct position, depressing the "toaster" handle carries the ballot into the "read" position and initiates a delay.

(b) Read. As the ballot comes into the "read" position, the contacts in each row cause the stepping switch connected to them to advance the number of steps that correspond to the number of pulses received. The stepping switch arm now rests on the contact number corresponding to that candidate's name and the ballot can be tallied.

(c) Tally. The delay has expired (the "orientation" hole in the card now is positioned to allow the "read" contact to make), and the scanning switch can now move in succession over the seven contacts. If there is a vote (i.e., a hole) at one or more of A, B, C, D, E, F, G, the scanning arm receives a pulse for each and

moves the stepping switch connected to H one step (one vote) for each pulse received.

(d) Too many selections? The output of the stepping switch connected to H goes through a relay-operated contact to a line circuit breaker. If the correct number of pulses are received at H, i.e., the correct number of candidates have been selected on the ballot, the arm will rest on the contact to which the output lead is connected. At the end of scanning, the scanning switch actuates another switch which closes the relay in the H output. If the number of votes is correct, the line circuit closes and the vote is tallied in the counters.

(e) Pop-Up. The "toaster" handle return mechanism can clear the card and reset all the stepping switches and scanning switch.

(f) Tilt. If the ballot is spoiled, the line delay circuit breaker remains open, rejecting the ballot to a "spoiled" bin for closer examination.

Simplifications and complications

1. If the incumbent is always number one on the ballot, one channel simplifies to a direct connection between A and 1.

2. If only one candidate is to be selected, the cards (ballots) can be automatically retained in separate bins.

3. The counters would need locked covers if the tallier were used in place of a ballot box.

4. The county could rent lines to total, either verbally or automatically, the votes from all precincts at the close of the polls.

5. If used in a polling booth, the "toaster handle" return mechanism could actuate a signal to prevent "stuffing".

Observations

1. No electronic tubes.
2. All items are commercially available.
3. No power pack is needed.
4. The system calls for no special manufacturing technique and no highly skilled maintenance personnel.

M. T. Gardner
26 Woodland Ave.
Dartmouth, Nova Scotia

FEEDBACK

(Continued from page 8)

retain or recall the required number from sales, detailing, and outside enterprise. The engineers so gained are apt to be among the top in ability. They are the ones who did not need "security" or "team" action. They could solve problems themselves and they stepped out on their own.

I believe that more data is required before your assumption of "shortage" is proven and in the meantime statements should be tempered.

John M. Graham, P.E.
Bellwood, Ill.

Mr. Graham's comments make jangling counterpoint with the now-completed series of McGraw-Hill editorials on "The Shortage of Scientists and Engineers". But point and counterpoint come to a swelling agreement on this chord: "analyze jobs to relieve engineers and scientists of routine work". Ed.

Fresh French look at servos

TO THE EDITOR—

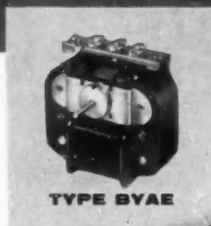
I just happened to get the recent book entitled *Feedback Systems Theory and Design*, by J. C. Gille, N. Pelegrin and P. Decaulne, which has just been published by Dunod in Paris, France.

My first reaction was to think, with a shade of discouragement, "One more book on servo . . . is this the hundredth or the thousandth in the past few years?" And I was prone to as-

THE MARK OF QUALITY



Small Motors



"We reduced our motor costs 85% on this servo application."

Robert K. Seigle, Project Engineer,
Hycon Electronics, Inc.

Here's another example of how many manufacturers today are improving their products while reducing component costs through the utilization of Barber-Colman small motors. Counters on the Hycon digital voltmeter and the Hycon digital ratiometer, previously driven with aircraft-type servo motors, are now powered by Barber-Colman type BYAE motors at a fraction of the former cost. And operating performance has been equaled or improved by this change! Along with cost-reduction considerations, Hycon Electronics, Inc., Pasadena, California, selected Barber-Colman high-torque reversible motors because they are designed for control by electronic circuits with impedance coupling, and low-inertia rotors permit fast reversing and follow-up. If you have a design problem involving small motors, let Barber-Colman Company engineers help you solve it with the exact motor for the job.

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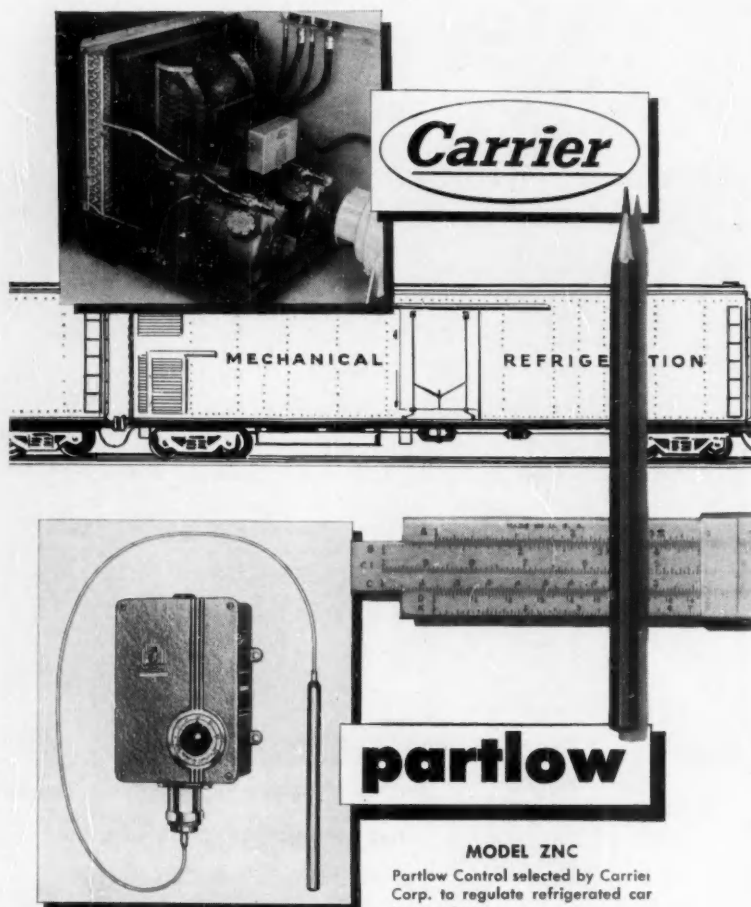


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FEEDBACK

sume that the ambition of that 724-page and 6-lb book would be to gather together all that has been said up to now concerning servo theory.

But I very quickly became aware that this was not the case; in fact, before me was a book entirely new with respect to what has been published up to now concerning feedback systems.

F. H. Raymond
Societe d'Electronique
et d'Automatisme,
Seine, France

This burst of enthusiasm from M. Raymond, chief engineer of SEA and president of the First International Conference on Automation which convened in Paris last June, merits the attention of control engineers in this country. If it whets your appetite, turn to page 178 of the New Books section for his complete review.

Ed.

Can an inchworm make gears?

TO THE EDITOR—

Your *What's New* column in the September issue of CONTROL ENGINEERING noted the application of Airborne Instruments Laboratory's Inchworm motor to a machine tool.

We are interested in obtaining additional technical information on this unit and its adaptability to machine tools. Any information would be greatly appreciated.

M. D. Barker
Gleason Works,
Rochester, N. Y.

Airborne Instruments Lab replies that there is presently only one model of the Inchworm available and claims that it is adaptable to most types of centerless grinders, or for that matter, to almost any machine feed requirement in which:

- thrust loading is below 500 lb
- travel does not exceed 9½ in.

The stated limitations are those of the specific standardized design. Load capacities and travel capabilities will be expanded as the market requires.

The \$2,500 purchase price for a model to be used on a Cincinnati #2 Centerless Grinder includes the Inchworm motor, the hydraulic pressure pack for actuating the motor clamps, the electrical assembly for semi-automatic operation of the motor, and the flange casting for mounting the motor on the grinder. Accessory kits that include gage and logic components to make the typical system fully automatic range in price from \$1,200 to \$2,500. Ed.

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Heart of the system is a remarkable gyro stabilized platform of such stability that the slightest variation in windage or missile velocity can instantly be sensed and precise corrections made.

This great new development is one phase of AC's work as a prime contractor for the Air Force Ballistic Missile Program. It is one more example of AC's leadership in the field of electro-mechanical research and development.



THE ELECTRONICS DIVISION OF GENERAL MOTORS

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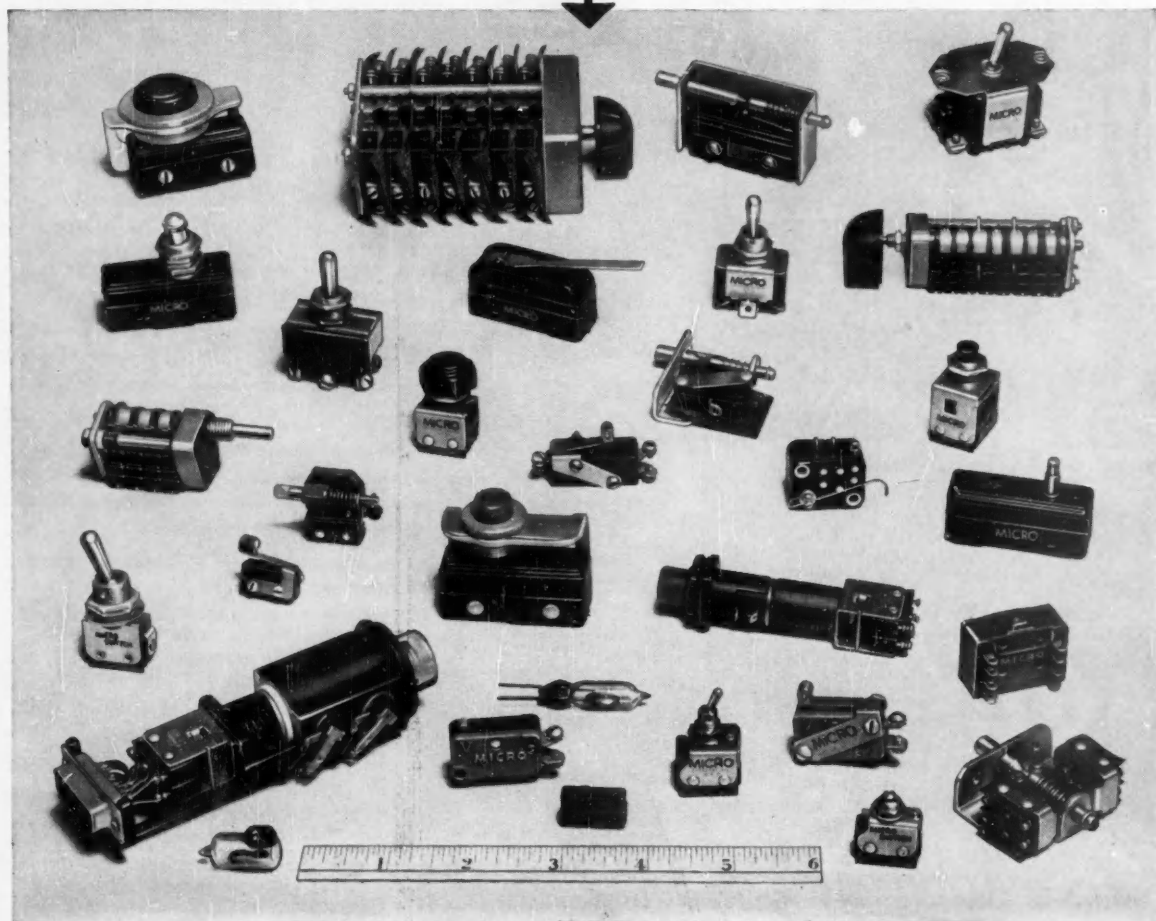
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meet wide range of modern
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Design engineers find MICRO SWITCH precision switches to be ideal components for computers, high speed switching devices and other industrial devices.

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specialists have met successfully many knotty problems of switch design and application. This long, practical experience will save YOU time and money.

A call to the nearest MICRO SWITCH branch office will put MICRO SWITCH Field and Factory Engineering to work on your specific problem. This cooperation can be your short cut to improved design.



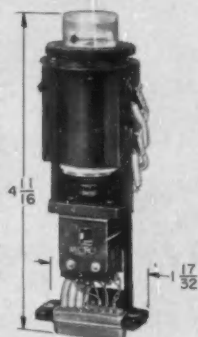
Switches have uses unlimited



3-LIGHT PUSH BUTTON SWITCH FOR COMPLEX CONTROL PANELS

Here is a new, unique indicating push button switch which lights in three different colors. It is the latest MICRO SWITCH development for use in complex console panels. This compact assembly is ideal for applications where absolute dependability is required. It has a reliable operating life through hundreds of thousands of operations. Use is simplified by a pre-wired connector plug.

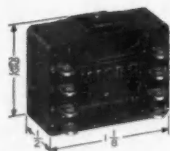
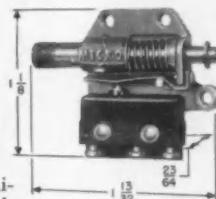
(Send for Data Sheet 110)



SUBMINIATURE SAFETY SWITCH DEVICE FOR HAZARDOUS EQUIPMENT

This MICRO SWITCH Subminiature door interlock switch assembly is designed for use as a safety device on such hazardous equipment as radio, radar, and X-ray cabinets. Installed on the cabinet door the switch automatically cuts off the power circuit when the service door is opened. Assembly shown uses a MICRO SWITCH Subminiature basic switch with single-pole, double-throw contact arrangement.

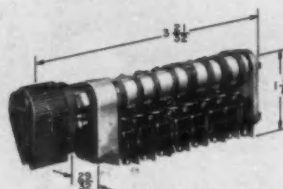
(Write for Data Sheet 108)



FOUR-CIRCUIT SWITCH FOR CONTROL OF COMPLEX CIRCUIT

Here is a four-circuit double-break switch for simultaneous control of four isolated circuits. This small switch is ideal in complex circuit applications where space and weight are prime factors in switch selection. Two snap-action springs are operated with each actuation of the plunger. This provides quick make and break of the contacts in each of the four double-break circuits. Electrical rating is 10 amperes 115-230 volts a-c; 10 amperes 30 volts d-c.

(Write for Catalog 78)



SUBMINIATURE ROTARY SELECTOR SWITCH FOR MULTIPLE-CIRCUIT CONTROL

This assembly is an 8-gang, 8-position rotary selector switch. It consists of 8 single-pole, double-throw Subminiature basic switching units operated by cams on a common shaft. Any combination of the 8 basic switching units may be actuated in any of the 8 positions if cams are set to specifications at the factory. Variations with from 2 to 8 single-pole, double-throw basic switches are available.

(Write for Catalog 75 "Subminiature Switches")

SEALED PUSH BUTTON SWITCH FOR PANEL MOUNTING APPLICATIONS

This MICRO SWITCH push button switch for panel mounting is outstanding because of its very small size and ease of installation. After the push button is mounted on a panel, the switching unit can be wired and then easily snapped into place on the end of the button assembly behind the panel. In addition, the push button is sealed to keep dirt and moisture from penetrating to the back of the panel. Switch has operating force of 3 lbs., weighs but .05 lbs.

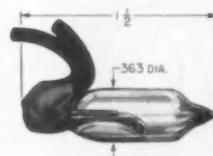
(Write for Catalog 75 "Subminiature Switches")



SMALL HONEYWELL MERCURY SWITCH MEETS SMALL LOAD CIRCUIT DEMANDS

The small Honeywell Mercury Switch shown here is especially designed for reliable service in low-energy circuits. This switch meets the requirements of applications where space and economy are critical factors. Mercury switches are widely used in animated displays, control and indicating devices, home freezer units, alarms and hundreds of other tilt-motion, low-force applications. Ratings available down to micro-volt, milli-ampere ranges.

(Write for Catalog 90 on "Mercury Switches")



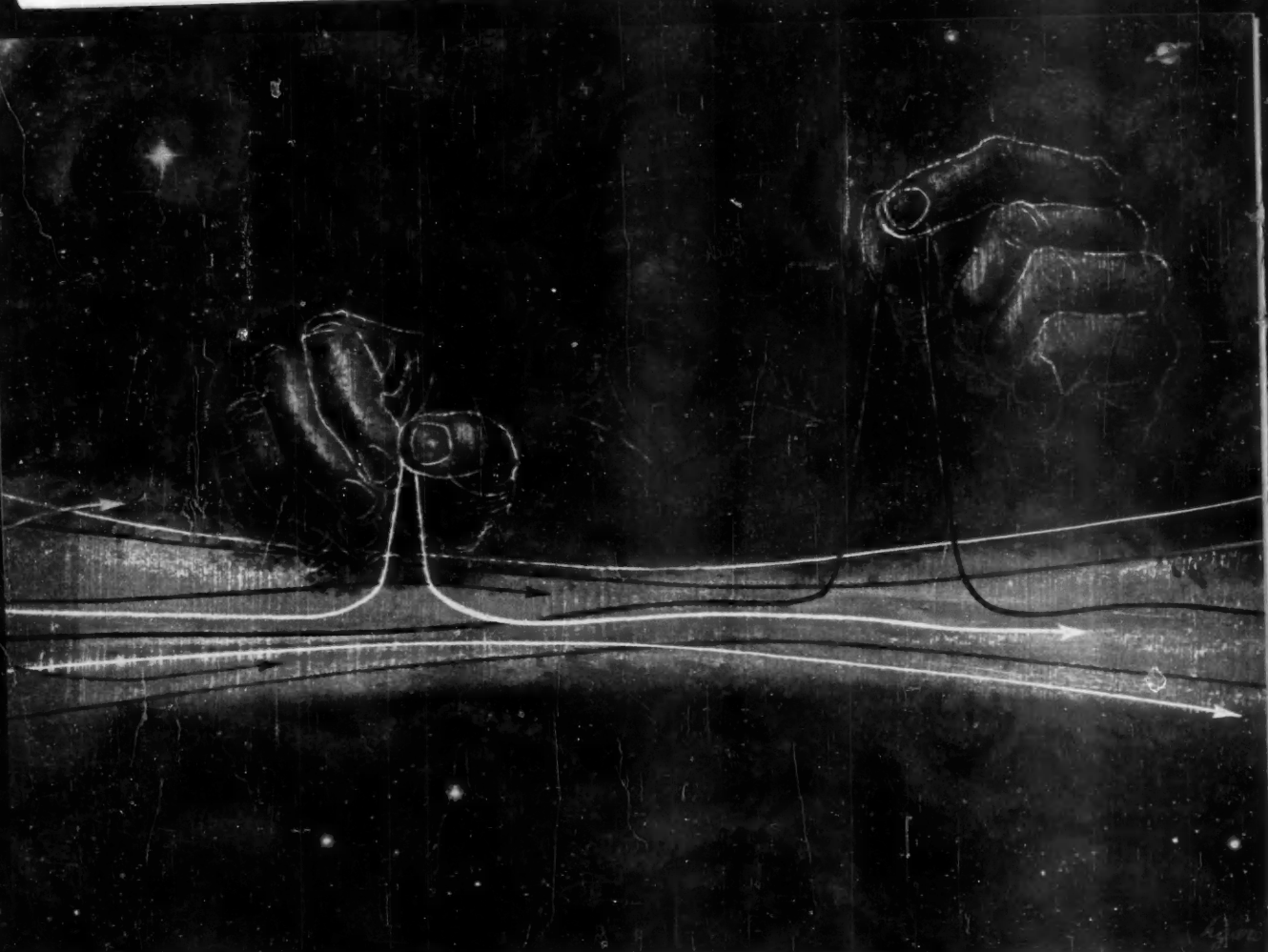
MICRO SWITCH, a division of Honeywell,
is the pioneer in the manufacture of
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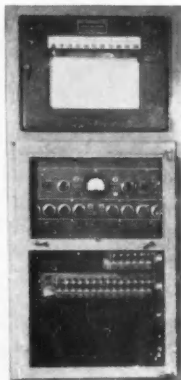


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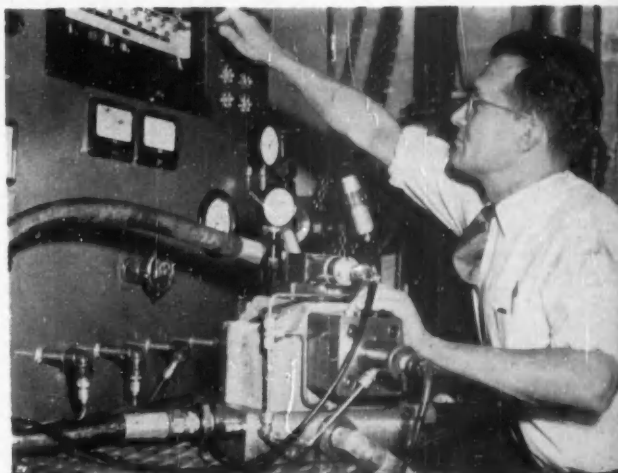
CHARLEY CLOSE insists on analysis

Back in '39 while locked in mortal combat with a pair of massive, balky butterfly valves on a customer's water reservoir control system (third order), Charley Close threw down his screwdriver, tore up his home-made nomograph, and muttered, "There must be a better way." Ten years and a few hundred "seat-of-the-pants systems" later, says Charley, he saw the light: "It took Brown and Campbell, a few night courses at Brooklyn Poly, and a Philbrick computer to unseat my frustration. Now I'd sooner go back to playing patty cake than design a control system without first doing a thoroughgoing analysis and then objectively finding—or building—the right components for the job."

CDC Control Services, Inc., formed by Charley and a dedicated crew of 15 engineers in 1952, is a growing, gilt-edged proof that the purist approach to control systems engineering can pay off for a vendor. Today, with almost 200 systems in back of it, a staff of over 80 busily hews to the classic steps of analysis, synthesis, and test in the seam-bursting Hatboro, Pa. facility. "And," stresses President Close, "we are now in a position where we can insist on dynamic analysis as part of a system package before we accept an order."

Charles Dolbow Close's drawl and his reference to engine test facilities and wind tunnels as "processes" are a dead giveaway to his apprenticeship in the well-known pre-war Philadelphia school of industrial process control. He was born in that city in 1914 and took his BS in EE from Drexel Institute in '36. For the next eight years Charley learned instrument lore "the hard way", designing and installing control systems in local chemical plants and oil refineries for the Sheffer-Gross Co.—a multi-product sales agency that specialized in valves and actuators. Close became an expert in getting the most out of actuators. But he also became acutely aware of the blanket rules and traditions that determined actuator design and selection (CtE, Sept. '55, p. 97).

During the war Charley Close went into the jet pump manufacturing business and also created and operated Fluid Controls Co., an east-coast control equipment sales agency. In '50, after exposure to the systems engineering virus, he took on a subcontract for a jet engine altitude test control system at the Naval Air Turbine Lab in Trenton, N. J. It was one of the first performance contracts to include dynamic characteristics of all components. The analytical study was made on a Philbrick computer by John Hrones' group at MIT, and component tests took place in a 1/100th-size process simulator at a compressor lab in Bridgeport, Conn. The complete job—it took four years from study to use—was pleasantly profitable and perhaps the main reason for establishing CDC.



Charley hovers over one of his "right" components—a new electrohydraulic actuator on a dynamic test rack.

In its four years of growth CDC has carried off many successful jobs in the air facility test and simulation field (NACA wind tunnel control, Thompson Products engine test facilities, Wright Aeronautical engine test and compressor surge control). But one big question troubled Charley and his co-managers: how were they to emphasize CDC's unique ability in the more traditional and competitive industrial process control market? Last spring they came up with an intriguing answer: a trademarked elaboration of CDC—CompuDyne Control—and a sales approach that places systems engineering on a true product basis. Now, when a customer places an order with CDC, he understands that the costly engineering analysis that must be done is a definite part of the "product". "Free engineering," advises Charley, "even when restricted to 'pushing a component line', is the big reason why many industrial control firms show a less than healthy profit."

Friendly, intense, and infinitely curious, Charley Close projects his interest in analysis well beyond the needs of processes and machines. His hobby, he admits, "is really understanding how people act in relation to their environment". When not at home responding to the needs and interests of his wife Gladys and sons Ricky and Roddy, Charley volunteers many hours to a nearby hospital, where he does classified work involving the dynamic measurement of intellectual speeds. "There are frequency response data to be taken on all phases of our society and life," says Charley. "If we strive towards an optimum in any pursuit—be it control, business, or better human relations—we must always start with analysis."



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2600	0-60	0-2 Amp.	5 Mv.	5 Mv.	1 Mv.	50 μ sec.	10 Mv.	0.002 Ω	0.0005 Ω	19"	10½"	17"	\$690
2650	0-60	0-5 Amp.	5 Mv.	5 Mv.	1 Mv.	50 μ sec.	10 Mv.	0.001 Ω	0.0002 Ω	22½"	28"	19"	\$1190

Good stability
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POWER REQUIREMENTS: 105-125 volts, 60 cycles.
FUSE PROTECTION: Input and output fuses on front panel. Time delay relay is included to prevent unregulated voltage from appearing at the output terminations.

OUTPUT TERMINATIONS: DC terminals are clearly marked on the front panel. Either positive or negative terminal of the supply may be grounded. DC terminals are isolated from the chassis. A binding post is available for connecting to the chassis. All terminals are also brought out at the rear of the unit. Two terminals are mounted at the rear of the chassis to provide for picking up the error signal directly at the load. This connection compensates for the voltage drop in the wires (and ammeter) connecting the power supply to the load.

METERS: Ammeter: 0-2 amperes, 4" rectangular for Model 2600
0-5 amperes, 4" rectangular for Model 2650

Voltmeter: 0-60 volts. 4" rectangular

CONTROLS: Power on-off switch, DC on-off switch, remote error signal on-off switch, coarse and fine voltage controls. The coarse voltage control is a ten turn potentiometer which varies the voltage from 0-60 volts. The fine voltage control is a ten turn potentiometer which varies the voltage 1 volt. The voltage divider network allows a 61 volt variation in output voltage.

*Recovery time is less than 50 microseconds. The excursion in the output voltage during the recovery period is less than 50 millivolts for line fluctuations from 105-125 volts or load variations from 0 to maximum current.



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1957:

Two Control Developments Begin Their User-Trials

1. Machine tool control—by numerical positioning and by static elements
2. Industrial process supervision—by integrated automatic data reduction

The year 1956 was an exciting and productive one for the control field. A glance at CONTROL ENGINEERING's Annual Index (Dec. '56, pages 183-190) reveals the specific progress. Most impressive—both in sheer volume and variety—are the commercial success stories about systems: 1956 may well be known as the year that the tools and methods of control systems engineering were first put profitably to work on a broad scale. The systems listed in the Index range from the spectacular to the modest. They include control for a shipboard nuclear-driven gas turbine (Oct., page 71), in-line industrial process computation (Nov., page 83), and analog control of a large electrical power network (Dec., page 77).

Along with systems progress last year was the promise of new control techniques—the means for catalyzing and improving systems in our field in the forthcoming years. Among the trends were a concerted emphasis on digital measurement, a growing use of solid-state devices in design, an increase in response and power in actuators through hydraulics, a perfection of continuous product analysis. In our scan of the '56 Index, however, most of these new techniques seem to channel—through use—into two major field developments which may well capture progress "honors" in 1957:

- the mobilization on automatic control in the machine tool field
- the integration of automatic data logging in the process field

Vague rumors about new systems for controlling machine tools became authentic fact in '56. In this single year more than 20 different companies—mainly instrument and control makers—announced commercial developments ranging from two-axis numerical table positioners through static-device program "packages", on to automatic gaging and inspection systems with feedback control. Product from one of the newest contenders

in the field (Reeves Instrument) is pictured here and on page 22.

Automatic data logging, on the other hand, was well beyond the "rumor" stage in '56: at least ten makers were actively pushing complete systems in the industrial process markets and comments on performance were coming back from the first users (see *Industry's Pulse*, page 59). One of the latest entries in the logger market is pictured below.

A broad field development—

"trends" if you will—machine tool control and automatic process data logging have several things in common. Both are characterized by an almost frantic, "bandwagon" haste by makers to enter the field. Both have created a user interest that dominates technical meetings throughout the country. And both, because of little user-experience, face a formidable year in 1957, when concept, design, performance, and—above all—economic justification—will all be on trial.

FOR STATUS REPORTS ON THE TWO DEVELOPMENTS SEE NEXT 8 PAGES

TWO NEW CONTENDERS IN THE FIELD:

REEVES INSTRUMENT has just unveiled its new servo-controlled three-axis positioning system. The machine shown—a four-head Bridgeport drill—is turning out parts in the Long Island plant. More on page 22.

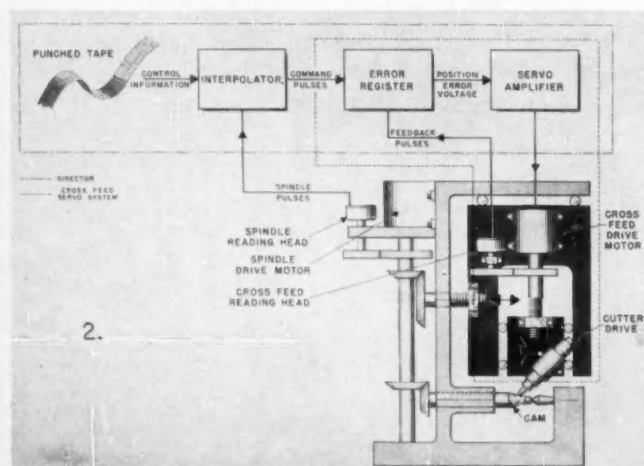
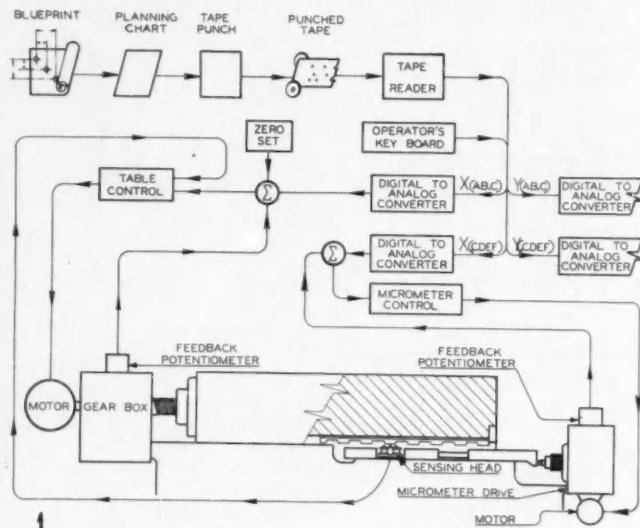


HANSON-GORRILL-BRIAN offers this handsome new universal logger with building-block design. It was displayed for the first time at the Automation Show in New York (Nov. 26-30).



1. Unrevealed Specifics Retard Machine Tool Progress

But, reports Byron Ledgerwood*, when the control makers, machine tool builders, and the ultimate users get together, the discussions are enthusiastic and free-flowing. Some extensive field testing in the next few months should dispel the "secrecy".



* Senior Associate Editor, Control Engineering

"The 'state-of the art' in machine tool control can be best summed up by what I heard and saw at the eighth AIEE Conference on Machine Tools in Cincinnati last Oct. 22-24. Each conference before this one had seen a steady build-up of interest in programmed machine tools. This one topped them all, with nine out of 12 papers focused on numerical control. There was also a panel session on static control elements—the other 'hot' item in machine tool control right now. About 600 people came, including practically everybody with an interest in numerical control—certainly everybody that I know.

"Although the technical level of this particular AIEE conference may not be as high as other AIEE meetings, it is among the most interesting because of the uninhibited type of man (machine tool builder and user) who comes to it. Discussion flows freely and often sharply in contrast to the stodgy, often dreary discussion periods held at some meetings.

"One thing struck me immediately as the discussion on numerical control proceeded. It is true that this was a data processing meeting and everyone was willing to talk long and loud about how their equipment processed the data. But when specific questions were asked concerning driving the machine tool or feeding back positional information, speakers became strangely quiet. This soon became a joke, since people like Harry Mergler of NACA almost invariably asked for detailed information and was usually answered with some ambiguous or indefinite comment, or else given a frigid 'no'.

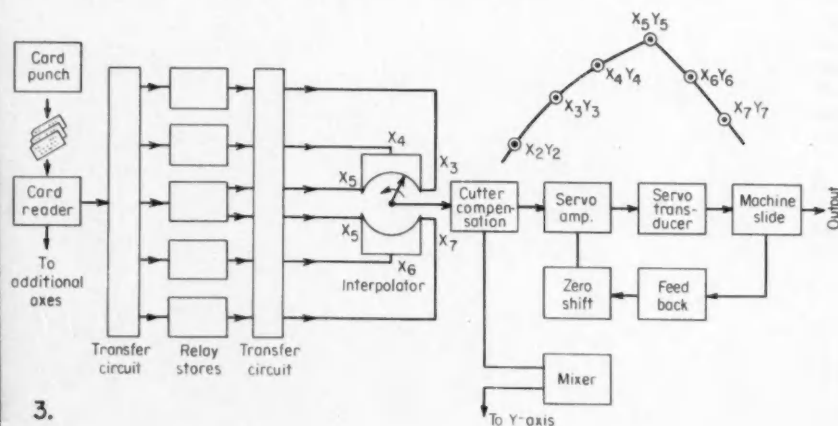
"It seems to me that this 'coyness' about control specifics is highly questionable since the makers were talking to many of the people who will be their customers. It is doubtful that any of the systems use techniques so unique that the speakers' companies would have suffered due to direct answers. Actually, if one of the speakers had talked frankly he probably would have swayed the audience an undefinable amount in his company's favor.

"The first paper on numerical control was a general review by Ralph Schuman of Warner & Swasey. Although Ralph's group has not announced a system it was obvious,

(Continued on page 22)

(Continued on page 22)

* Senior Associate Editor, Control Engineering

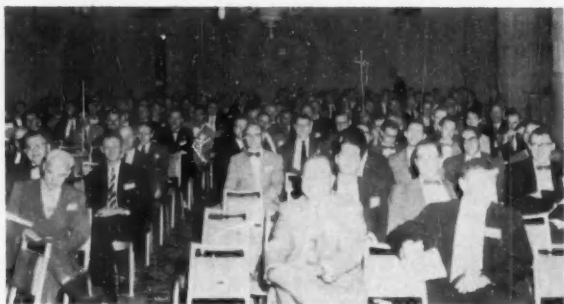


THREE OF THE SYSTEMS

1. PRATT & WHITNEY'S numerical control system is designed for jig borers and jig grinders with the required orthogonal axes and utilizes a highly accurate magnetic bar position measuring system. It positions in one direction only.

2. BENDIX AVIATION'S numerically controlled cam machine uses an inductive coding disc to convert its tape program into 0.0002-in. cross-feed movements. A synchro receiver at the cross slide generates voltages for feedback control.

3. CINCINNATI MILLING'S employs toroidal transformers for measurement and uses interpolating circuits and stepless switching techniques. The block diagram shows a single axis of this system.



Makers and users sit side by side at this ISA session on data logging in Philadelphia. An equipment exhibit (right) was part of the two-day symposium.



2. Data Logging Measures Up to Industrial Needs

But, comments Lloyd Slater*, there are disturbing as well as reassuring reports from the first users in the process control field. During conclaves there is visible groping by the designers for what is right and how to justify it.

"This month's *Industry's Pulse*—see page 59—offers a revealing picture of the present and prospective user attitude toward automatic data logging. To distill a realistic 'trend' about the present and future of this new technique in the process industries, however, you still have to bring the manufacturer's attitude into the picture. The means for this distillation was admirably presented during the recent (Nov. 7-8) Symposium on Automatic Data Logging Systems conducted by the Philadelphia Section of ISA in a ballroom of that city's Bellevue-Stratford Hotel.

"About 300 people turned up for the symposium, many of them process control engineers from the huge chemical and petroleum operations that surround Philadelphia in a dense 100-mile-deep industrial area. Engineers from the maker firms were there in force, too: the city and its suburbs house the largest industrial process control manufacturing contingent in the country. So the audience was 'sharp'. When a user asked a question—and two-thirds of the questions were from users—it related to the very real needs of his plant and usually was prompted by direct or second-hand experience with a pioneering logger installation. And when a maker-engineer sent a query to the podium it was usually bristling with a controversial nuts-and-bolts aspect of logger design.

"The Philadelphia Section cooked up a good working program. Roughly half of it was devoted to a practical evaluation of building blocks for automatic data logging systems: transducers, converters, output devices. The other half assayed today's working systems and tried to focus on the needs which will shape tomorrow's developments.

"What were the important issues? Three things, it seems to me, came out of the discussions:

1. The urgent need for improved measuring techniques to better utilize the potential of automatic data logging.
2. The apparent need for much work on system and component reliability—most user comments stressed shortcomings in this area.
3. The tacit agreement that the automatic data logger is only a half-way measure—that the electronic computer must ultimately tie into the system.

"When the makers spoke they held to the practical line of cost and design. John Werme of Metrotype (now a new division of Bailey Meter Co.), for example, concentrated on how the user could save money in setting up proper transducers for his data logging system. He flung provocative questions. Are suppressed ranges necessary? Why don't you standardize on one type of flowmeter to get uniform signals? What about thermocouples—won't one type do over its complete range (rather than inflicting CC, IC, CrAL, etc., on your system)? Werme's point: if the user drops traditional attitudes in selecting his measuring equipment he can save a good deal of money and complexity when setting up his logging system. But, stressed Werme—and several other speakers—there is no substitute for designing your control system and your logging system together—and with the advice of a data logging expert.

"John Werme brought out one more intriguing point. Why not, he said, get the most out of your logger by bringing in normally uncollected—but vital—information by, for example, tying in simple switches, tachometers, etc., on important plant equipment such as pumps, motors, gates?

(Continued on page 36)

* Managing Editor, Control Engineering

COSTS IN BLACK AND WHITE

Phil Gilman of Taylor got right down to cases when he blackboarded the price of a graphic panel and then estimated how much an equivalent data logger would cost. Fact: while the logger costs five times more, it pays off much faster, says Phil.



Use...

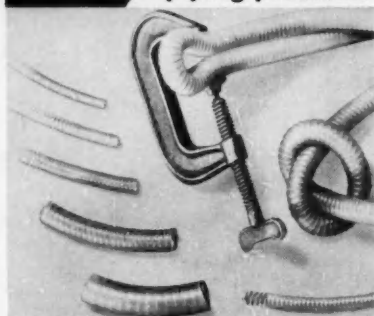
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WHAT'S NEW

(Continued from page 20)
from his paper, that they are familiar with all phases of the problem. I'd say that there is plenty of activity at W&S—and that they will be out with one of the finest systems very soon. Aside from his thorough basic review of design problems, information introduction, and storage methods, Ralph stressed the increased use of numerical controls, which he said will eventually force the basic redesign of machine tools to fit them for optimum automatic performance.

"Next Baldwin of GE and Tholstrup of Commercial Controls Corp. surveyed the types of information storage devices available for machine tool control. An intriguing comedy act occurred during the discussion period that followed. One of the old-timers in the machine tool industry wanted to know the difference between a 'bit' and a 'character'. Several answers were given in succession—each complicating the preceding one. It went on until I am positive that the old-timer got to the point where he may

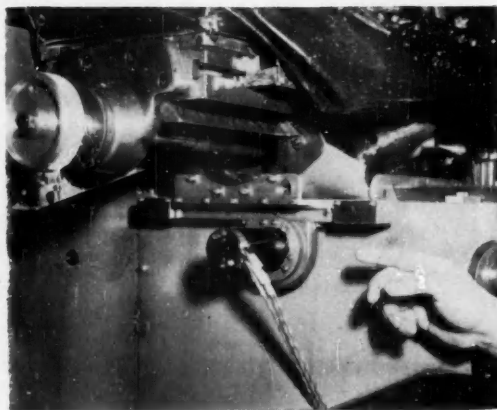
never know the difference, and probably many people who thought they did are now not quite so sure.

"Kenneth Wood of Boeing next outlined some aircraft industry thoughts on the utility of numerical control. He told how the Aircraft Industries Association Subcommittee on Numerical Control found that a typical part, normally requiring 23 days from drawing stage to finished machining by conventional tracer control, could be completed in half a day using automatic computing equipment and a numerically controlled spar mill. Machining time alone on this piece was reduced from 2.5 hours to 0.25 hours. Wood pointed out that even if half these gains were achieved in day-to-day production, the impact of numerical control on the frame manufacturing industry would be tremendous.

In aircraft—it's justified

"Wood went on to list other possible gains: the ability of numerical control to hold the extremely fine

MORE DETAILS ON THE NEW REEVES UNIT

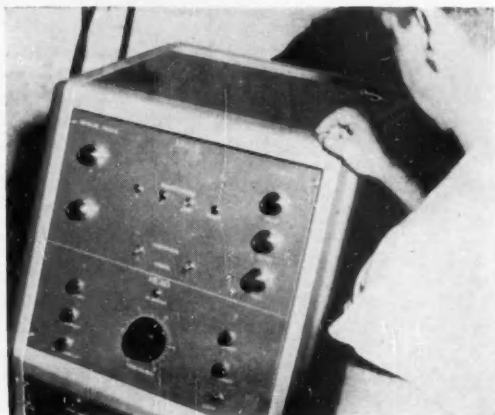


MEASUREMENT

Table position in both X- and Y-axis is measured with Reeves resolvers. Pickup is through a rack and pinion. Accuracy is said to be within 0.002 in. The voltage signal generated by the resolver is compared to the command signal which drives the servomotors on the table. Z-axis or tool vertical is measured by a pot and tachometer.

THE CONSOLE

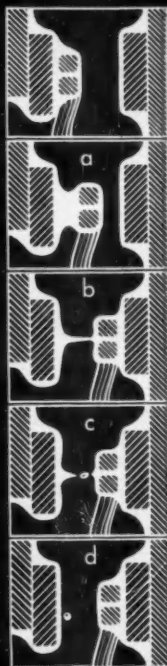
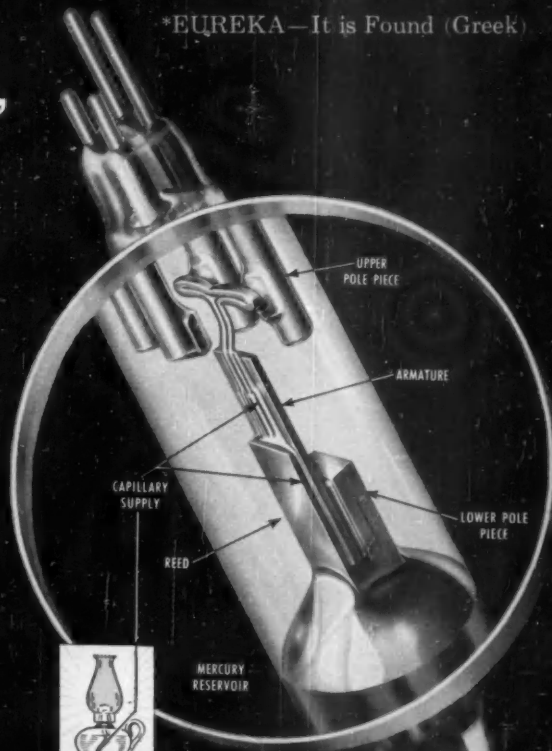
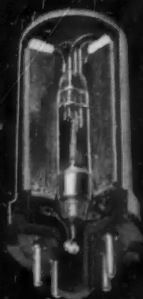
Originally, Reeves designed its system and console for the Bullard Co.—a project that was not commercialized. The original console used pots to dial in piece dimensions. The one on the right has program adjustability only through the back of the console—via a transformer and stepping switch.



EUREKA*

INDUSTRY FINDS A "FOUNTAIN OF YOUTH" IN THIS SELF-REJUVENATING CLARE RELAY

*EUREKA—It is Found (Greek)



Drawings (left) from stroboscopic photographs show the cycle. (a) Filament of mercury forms between the contacts as they separate. (b) This becomes narrower in cross section and (c) finally parts at two points, allowing a globule of mercury to fall out. Mercury flows up the capillary path, replaces amount lost, restores the equilibrium. (d) The momentary bridging of the parting contacts—and the extremely fast break that ends it—minimizes the arc and adds greatly to contact load capacity. Contact closure between the two liquid surfaces bridges mechanical bounce and prevents any chatter from appearing in the electrical circuit.

Ponce de Leon failed in his quest for a "fountain of youth," but modern design engineers find rejuvenation an accomplished fact in CLARE Mercury-wetted Contact Relays... capable of billions of operations.

Contacts of these relays are constantly renewed. By capillary action, like that of a lamp wick, a new film of mercury coats the contacts with every make and break.

The magnetic switch is sealed in a high-pressure hydrogen atmosphere in a glass capsule. Surrounded by the operating coil, the capsule is enclosed in a vacuum-tube-type steel envelope.

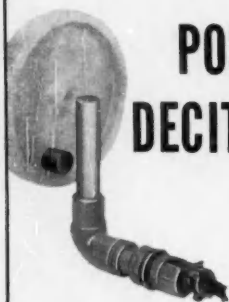
Unlike ordinary relay contacts, these contacts never wear out; never get dirty; never lock or weld; never get out of adjustment; never bounce.

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"Bounce" is eliminated by using a capillary film of mercury. For timing . . . synchronizing . . . or counting . . . specify the dependable, long life — MH-2. Write for literature.

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WHAT'S NEW

tolerances needed to minimize weight in supersonic aircraft titanium and steel wing spar sections; the removal of design compromises normally due to tracer control techniques; the lack of fatigue or hangover in control equipment, which contributes to excellent part reproduceability. Wood did indicate one problem facing numerical control: the fact that many shapes now used in aircraft are not mathematically designable. He pointed out, however, that a foreign aircraft maker has designed 1.5-million points on the skin of its product and looks forward to the time when these skins will be machined on numerically controlled equipment. The average machining tolerances quoted for numerical control were plus or minus 0.005 in general, and plus or minus 0.001 for hole centers. It was brought out later that the aircraft industry has already ordered 140 numerically controlled skin mills, spar mills, and other types of profilers—embracing a total of four or five different systems. One hundred of these machines will be delivered before the end of 1957.

"In the next paper Kenneth Jensen covered the programming of the well-publicized Giddings & Lewis Numerical system, which is a cross-breed between the numerical director developed at MIT and the recorded-playback developed by GE. He pointed

out the difficulty of programming complex workpieces without automatic computing equipment and referred to the work done by Siegel (CtE, Oct. 1956, p. 65). Incidentally, we were the only publication mentioned from the podium.

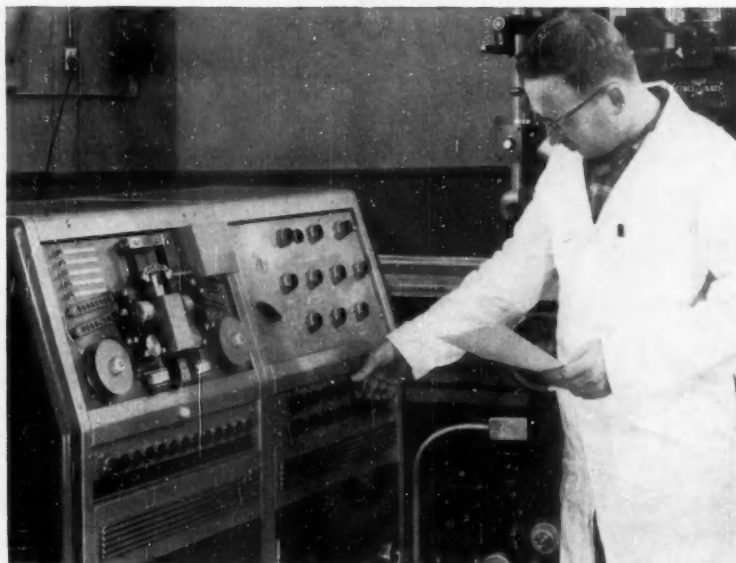
"Kirkham of Pratt & Whitney was the only one to describe discrete position programming systems where the location of successive points in two coordinates, rather than path transfers, is the important thing in getting from point to point. This system—see block diagram, page 20—is extremely accurate due to the proven measuring capability of P&W's well-known *Electrolimit*, which was adapted for numerical programming. It will position a jig bore to within 0.0001 in.

A user-developed system

"John Bower of the Autonetics Div. of North American Aviation discussed the only numerically controlled machine developed by a user. This particular unit—see cut below—was adapted for both two-dimensional continuous contouring and two-coordinate discrete positioning. So far it has not been used for productive work, but has been used for machining templates and similar items that will in turn be used on contouring machines for actual production.

"Jack Rosenberg covered Electronic

STILL ANOTHER NEW SYSTEM



Pictured above is North American Aviation's Autonetics Div.'s new numerical machine tool control tape-reading console. The transistorized control system has been used for automatic template milling in the parent company plant. An interference-type digital gage provided 0.0005 in. measurements over 8 ft or more of machine travel.

This old codger safely gages pressure by instinct... BUT



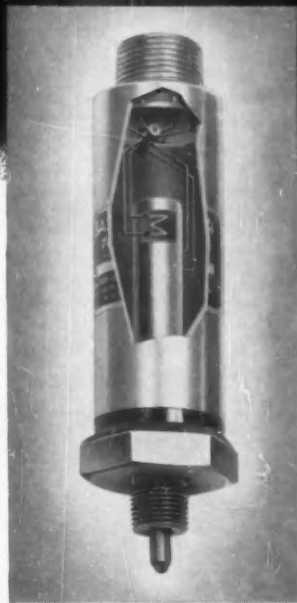
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controllers or data processing instruments—for our fishy friend, it could even activate a servomotor that would angle his fins downward and take him out of danger.

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RAMBLINGS ON INSTRUMENTATION



No, Virginia . . .

Every time our engineers come across another ad for some such product as a "Little Giant All-Purpose Standard Basic Look-no-further Gas Sampling System," they quietly beat their heads against the wall.

And our walls have been taking such a beating lately we thought it was about time to put The Hays Corporation on record with some plain, homespun truths about gas sampling, a subject that seems to lie in a heavy smog of confusion.

Homespun Truth No. 1—No, Virginia, there is no Santa Claus in the form of a single, foolproof gas sampling system, which will work on all applications. Hays also offers standard systems especially designed for specific applications such as pipe stills, cyclone fired boilers, cement kilns, etc. At last count we had tried and discarded another 18 designs.

Homespun Truth No. 2—It takes a heap o' designing, a heap o' field work, a heap o' cut-and-try to make a gas sampling system click. In our humble opinion, sampling is much more of an "art" than a "science," involving the peculiar demands of each geographical location as well as the idiosyncrasies of the equipment to which a system is applied. For this reason, Hays standard systems are the product of thousands of hours of experimentation on

ing and high pressure; a standard PRV cannot be used. Yet, with the addition of a simple two valve flow restrictor assembly, we are able to use the experience-proved "cat" regenerator sampling system.

The mountain comes to Mohammed

Once upon a time one of our salesmen suggested that we charter an entire freight train, containing boxcar-size installations of our products and tour the country with it to show customers how Hays products work on the job. (This boy is no longer with us.) We liked the idea. But instead of boxcars, we have packaged our products individually in portable display cases that provide a working demonstration of the product together with explanatory literature. Already much in demand for ISA meetings, exhibits and training groups, they are also available for "desk top" private showings for you and your associates. Call your local Hays representative and he'll arrange it.

Anyone for Veriflow?

We are, if you'll excuse the expression, somewhat proud of our Veriflow meter and inclined to regard it as a rather versatile positive displacement flow meter. But recently we were astounded out of our socks at a list of liquids being metered by Veriflow users . . . it included water, heavy oils, molasses, tar, brine, ammonia, formaldehyde, acetic acid, phosphoric acid, sea water, carbolic acid, citric acid, chocolate, turpentine, et cetera. The versatile Veriflow can be equipped with multiple remote indicators, tied in with a standard potentiometer type recorder, packaged as a flow controller (we call it a Veritrol), hit the long ball, and go to its left. It is detailed in our bulletin 53-766-38. Like a copy?

Don't forget that mammoth \$10 award to the possessor of the oldest Hays Orsat still in operation . . . send in those serial numbers now, Orsat fans.

Phil Spagor, Jr.

Executive Vice President

WHAT'S NEW

Controls Systems' computing and control system for three-dimensional continuous contouring on a miller. This was the only continuous contouring system reviewed that is not specifically aimed at the aircraft industry; it is designed for general industry use. It also differs in that it includes a special-purpose computer which will handle straight lines and curves. This means that point-by-point programming is not necessary if the part to be machined includes only straight lines and circular sections—a common work-piece in most shops.

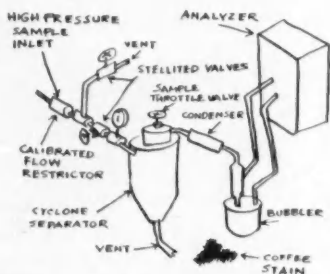
"The Bendix" paper, delivered by Robert Sims, dealt with two systems. One, the cam miller—see diagram, page 20—was specifically designed to produce three-dimensional cams, while the second is intended to control a three-dimensional miller. Bendix is the prime contractor for a numerically controlled system on a Kearney & Trecker machine and its control engineers are using this opportunity to influence the tool design to fit it to the static and dynamic characteristics of the complete system. The results should be interesting.

"The last numerical control paper, by Fuldner and Wilson, described a system developed by the Cincinnati Milling Machine Co.—see diagram, page 200. Unlike the other systems, which used digital techniques for the necessary computing operations in the director, the Cincinnati system is completely analog, precision toroidal transformers doing the computing and position measuring. An accuracy of one part in one hundred thousand is claimed.

"Actually, the Cincinnati system is a modification of the one developed by EMI in England—Cincinnati bought the American line. It will be interesting to see how it makes out in the face of all of the digital competition. When I visited the company's plant recently, experimental portions of the system set up for display purposes seemed to function very well. Incidentally, Cincinnati is an unusual machine tool builder: not only does it make its own machine tools, but also all of the control equipment that goes on them—both hydraulic and electronic—and even goes so far as to wind its own toroidal transformers.

STATIC CONTROL ELEMENTS

"A most revealing part of the conference program was a panel on the value and future of static switching devices in machine tool control. On



Tablecloth courtesy of the Willie Chong "Italian Village" restaurant, Michigan City, Ind.

many installations with the end result being simple, rugged systems which we know will work.

Take, for example, the sampling system for high pressure petroleum reforming installations (tablecloth sketched above). In this application, due to high dust load-

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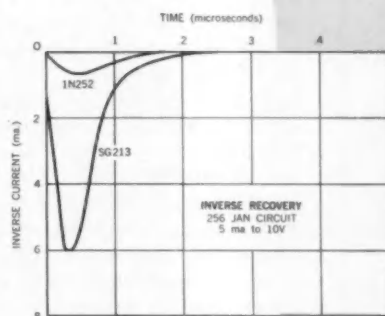
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Transitron's fast switching silicon diodes are intended for medium and high speed circuits in which diode recovery characteristics are important. These new types are considerably faster in recovery time than other silicon and germanium diodes. They are particularly useful in computer and similar applications.

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Type	Minimum Forward Current at 1.5V (ma)	Maximum Inverse Current (μa)	Maximum Inverse Voltage (Volts)	Maximum Recovery Time* (μsec)
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SG226	100	.25 @ 60V	80	1
SG223	30	.25 @ 175V	200	.5
SG221	30	.25 @ 60V	80	.5
SG213	5	.25 @ 175V	200	.3
SG211	5	.25 @ 60V	80	.3
Low Capacitance Types				
1N251	5 @ 1V	.1 @ 10V	30	.15
1N252	10 @ 1V	.1 @ 5V	20	.15

*Measured in the 256-JAN Recovery Circuit

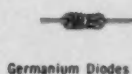


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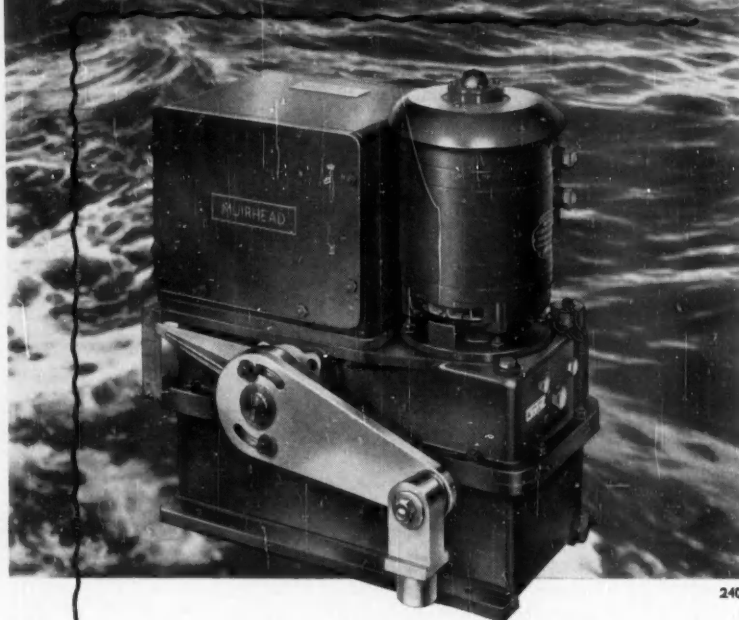
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T

MUIRHEAD**D-696-A****Hydraulic Relay**

240

This is a hydraulic amplifier, which, when controlled by a signal from a remote Magslip or Synchro transmitter, produces a mechanical output proportional to the movement of the control element with a great increase in torque but over a limited angle. It has been designed primarily to form the link between the gyro control unit and the fin-actuating mechanism in the Denny-Brown Ship Stabilizer, and produces a maximum torque of 40 lb. ft. The unit is self-contained, requiring only the connexion of a power supply to the pump motor and the necessary control signal to the Magslip receiver.

The equipment can also be arranged to operate on a mechanical input or control applied directly to the sensitive side of the amplifier. **GENERAL.** The Hydraulic Relay is constructed in an aluminum casting with a bottom flange for bolting down. The lower part of the casting contains the hydraulic unit, whilst mounted on top are the pump driving motor and the control mechanism. The output shaft projects from one side of the lower casting and carries a flange to which is bolted an arm. The flange fitting is arranged so that the arm may be fixed at any desired angle. A pointer attached to the arm indicates the angular deflexion and is also used for setting-up purposes. On the opposite side of the main casting are various preset controls and oil pressure check points.

WRITE FOR PUBLICATION 7727

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WHAT'S NEW

the panel were F. L. Fisher (Allen-Bradley), Jack Sheets (GE), Gerald Secor (Cutler Hammer), Paul Goudy (Square D), Oswald Bundy (Clark Controller), Paul Hanna (Westinghouse), and William Rote (Honeywell-Doelcam). As might be expected, the views of each rather sharply reflected what his company happened to manufacture (static devices or conventional relays).

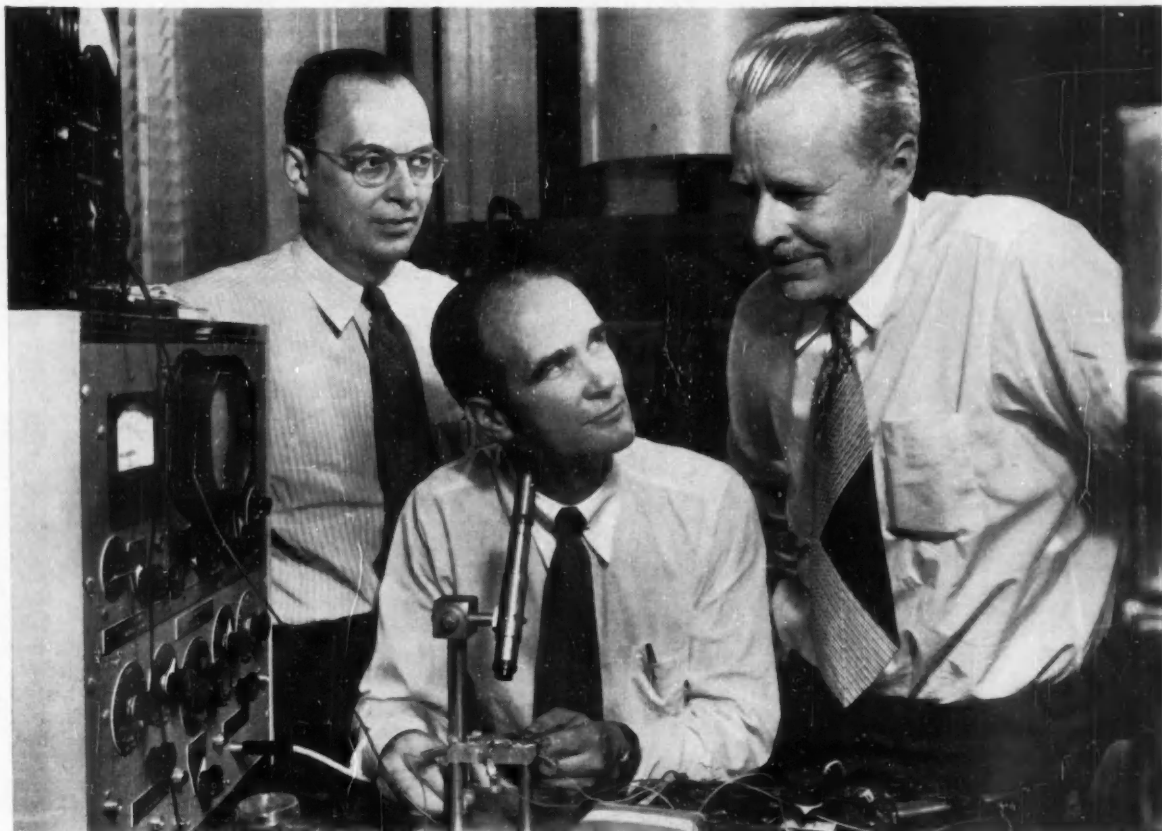
"Fisher of Allen-Bradley (which doesn't currently manufacture static switching devices) restricted his discussion to the advantages and disadvantages of static switching. Among the advantages: reduced maintenance; reduced space requirements; acquired operation; protection from environmental conditions. His list of problems included: repairs that are considerably higher in cost and beyond the ability of the average maintenance man; the questionable performance of individual components; the need to make quick changes to circuitry in the field without complete circuit revision; the need for new inputs because of the low voltage, low current demands of currently available static switching devices. His conclusion: the future system will probably be a combination of both electromechanical and static switching.

"Sheets of GE announced the company's two new lines of static switching devices. Its general-purpose static control elements, manufactured in Bloomington, Ill., corresponds almost point for point with the Westinghouse Cypak element, although there are differences in circuitry. Its static switching systems, manufactured by the Industry Control Dept. in Roanoke, Va., use bistable magnetic amplifiers. For example, in these units an AND function would be obtained by adding up the bias on a magnetic amplifier until it flipped. Of course, GE strongly advocated the use of static switching devices.

An "objective" approach

"Secor, of Cutler-Hammer, skirted the static switching problem by referring only to magnetic amplifiers used in modulating types of control systems. This left him sitting very neatly and securely on the fence. Rumors have it, however, that Cutler-Hammer will soon be operating with Westinghouse in the marketing of Cypak.

"Goudy of Square D, another non-manufacturer of static switching devices (with the exception of a proximity switch), paralleled Fisher's



(Left to right) Dr. John Bardeen*, Dr. William Shockley* and Dr. Walter H. Brattain, shown at Bell Telephone Laboratories in 1948 with apparatus used in the early investigations which led to the invention of the transistor.

Bell Telephone Laboratories Salutes Three New Nobel Prize Winners

Drs. John Bardeen, Walter H. Brattain and William Shockley are honored for accomplishments at the Laboratories

The 1956 Nobel Prize in Physics has been awarded to the three inventors of the transistor, for "investigations on semiconductors and the discovery of the transistor effect."

They made their revolutionary contribution to electronics while working at Bell Telephone Laboratories in Murray Hill, N. J. Discovery of the transistor was announced in 1948. Bell Laboratories is proud to have been able to provide the environment for this great achievement.

This is the second Nobel Prize awarded to Bell Telephone Laboratories scientists. In 1937 Dr. C. J. Davisson shared a Nobel Prize for his discovery of electron diffraction.

Such achievements reflect honor on all the scientists and engineers who work at Bell Telephone Laboratories. These men, doing research and development in a wide variety of fields, are contributing every day to the improvement of communications in America.

*Dr. Bardeen is now with the University of Illinois, and Dr. Shockley is with the Shockley Semiconductor Laboratory of Beckman Instruments, Inc., Calif.



Bell Telephone Laboratories

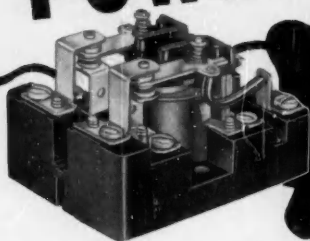
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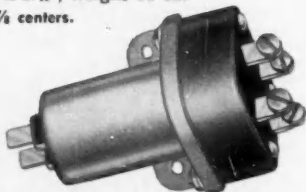


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Control more power in less space with this new Guardian 25 AMPERE A.C. Power Relay for motor starting, heater loads and other heavy duty applications. Standard unit has double pole, double throw contacts rated at 25 amperes continuous duty, 230 volts A.C., with 75% power factor. Operating power requirement is 9.5 VA.; coil drain approximately .080 amperes at 115 volts, 60 cycles. Two easily accessible screws permit removal and replacement of completely interchangeable coil assemblies rated at 6 V.-24 V.-115 V.-or 230 V., A.C. Relay measures $3\frac{3}{8}'' \times 2\frac{1}{2}'' \times 2\frac{3}{16}''$, weighs 11 oz.

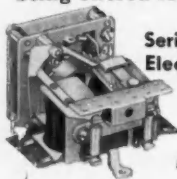
Mounting: 2 holes for $\frac{1}{2}''$ screws on $1\frac{1}{2}''$ centers.

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Designed and Tested for 230 V., A.C. Loads up to 3 H.P. Motors and 8400 Watt Heater Loads

A Guardian original—this new POWERLOID offers definite advantages which are far ahead of anything being offered for the electromagnetic control of motors and heater units. Available in a variety of contact combinations. Rugged, totally enclosed . . . low priced!



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*An electromagnetic switch
actuated by a solenoid plunger.

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"Everything Under Control"

WHAT'S NEW

comments, but showed more favoritism toward conventional relaying techniques. He pointed out the main problems of static switching as difficulty of plant maintenance and lack of design know-how. He claimed that Square D has accomplished as much by reducing the size, improving the life, and improving the contacts and fail-safe ability of conventional relays.

"Bundy of Clark Controller discussed both modulating magnetic amplifier applications and static switching techniques, making some of the most logical comments on static switching that were given by the panel. Although Clark Controller has never marketed a static switching system, it has extensively investigated both magnetic and transistor switching devices and, at one time, introduced a transistorized press control system. In press control work the most important point is the fail-safe ability of the circuit. This has been developed to a very high point in the electromechanical relaying circuit and Clark has circuits that will fail-safe regardless of how the equipment is jimmied. Bundy pointed out that obtaining these fail-safe features in transistor and magnetic circuits is extremely difficult because of cross wiring, bias wires, etc. I felt that it would probably be possible to duplicate the fail-safe feature of the electromechanical system using static switching devices, but only after extensive engineering work. His prediction: the use of relays and static elements will expand in proportion, with neither pushing the other out of the picture. A very sensible approach.

"Hanna of Westinghouse was on very secure ground because of his company's extensive experience and background with Cypak. Certainly the Westinghouse success has indicated that while static switching may not be the answer to every problem, it is certainly something to consider—particularly where reliability is important. Hanna announced that Westinghouse is by no means standing on its laurels—it is now working on high-frequency Cypak and transistorized switching systems. He showed a photograph of an experimental transistor network.

A case for proximity switches

"Rote of Doelcam had an interesting new approach to the problem. It seems that the major difficulty in machine tool sequencing systems is electrical and mechanical failures in the limit switches and in the relaying equipment. Doelcam, among others, plans to solve this with proximity

OOPS!

SIGHTS of rockets swooshing heavenward become more and more familiar as we thumb through today's industrial publications. The recalcitrant rocket shown on this page indicates that things *can* go wrong in research, and we don't claim that the absence of a Sanborn oscillographic recording system somewhere along the line was the reason for this disappointing trajectory.

What we do wish to say is that Sanborn equipment is playing an increasingly vital part in rocket development. Used in the laboratory to record flight behavior simulated by analog computers, and in plotting rooms at testing bases to tape down telemetered data, Sanborn "150's" are helping rockets to get and stay where they belong.

You can see Sanborn systems in many other places, too. Oil fields, electronic component production lines, machine tool plants, hydraulic testing laboratories, numerous aircraft manufacturers, computing facilities... are putting single to 8-channel Sanborn systems to work. (Most are housed in vertical mobile cabinets, while those in the "field" are often divided into portable packages for each instrument.) All of them give their users inkless, permanent recordings in true rectangular coordinates, one percent linearity, as many as nine chart speeds, and the efficiency (and economy) inherent in Sanborn unitized design. A dozen different plug-in preamps further extend their value, by making change-over to new recording inputs a quick and easy procedure.



SANBORN COMPANY

CAMBRIDGE 39, MASSACHUSETTS



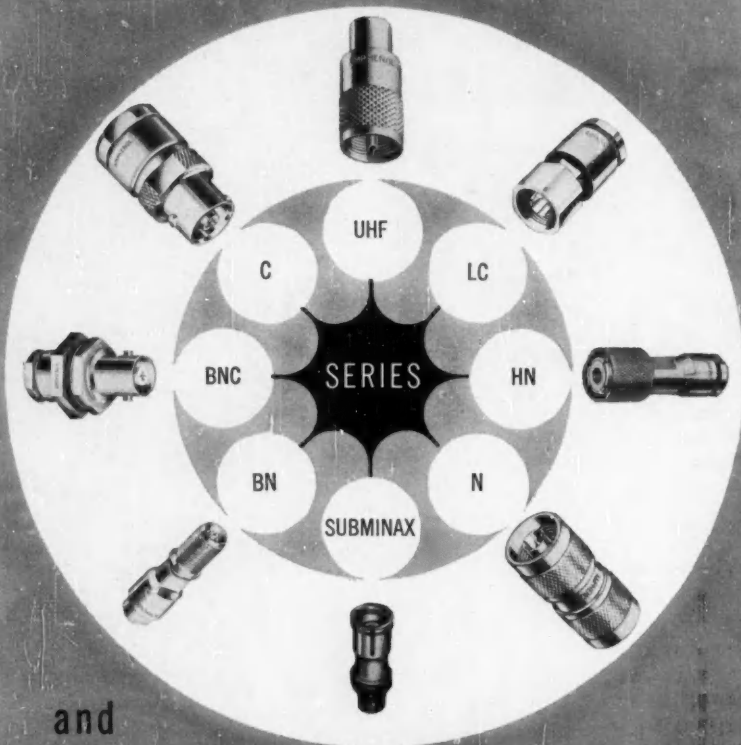
8-, 5-CHANNEL 4-CHANNEL 2-CHANNEL 1-CHANNEL 2-, 4-, 6-, 8-CHANNEL ANALOG COMPUTER SYSTEMS

Which way rockets are going may not be a primary concern of yours.

But if recording problems are, you're apt to find some interesting and useful answers in Sanborn's 16 page "150 System" catalog.

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*PATENT PENDING

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WHAT'S NEW

switches. However, the difficulties in this area now are the cost, size, and sufficient accuracy of available proximity switches. Another factor is the high cost of the static power amplifiers required to take the output of the rough elements and drive motor starter contactors, solenoids or hydraulic valves. This more than anything else is probably holding back the rapid expansion of static switching devices. Rote proposes to bypass this problem by building logic elements that will deliver sufficient power to drive a special on-off hydraulic variable. The techniques for this valve are borrowed from hydraulic servo experience; the input element will be a direct motor rather than a solenoid. Two-stage valves are, of course, required. Thus, the amplification will be done hydraulically and the system will be suitable wherever rotary cylinder hydraulic actuation can be used. Of course, if electric motors must be controlled, this system has the same problems as other static systems. But Rote felt that a system of combined magnetic and semi-conductor logic elements, or completely semi-conductor logic elements that could deliver one watt, would satisfy the valve input requirements. While Rote did not actually introduce a new system, rumors have it that Doelcam is taking a breadboard static switching system around to the machine tool builders to obtain future customer reaction.

"Some of the questions asked during the discussion period were of interest: ▶ Curtis of Warner & Swasey brought up the problem of the high cost of static switching devices and accused manufacturers of charging all that the traffic will allow. It was pointed out that the low volume production and the cost of winding toroidal cores brought the cost up. Actually the cost of the individual logic elements is not too high, but as indicated previously, output power amplifiers cost money.

▶ In answer to a question on the accuracy of proximity switches, Square D claimed plus or minus 1/100th in.

▶ During the panel session one of the participants had mentioned a down-time cost of \$1,000 an hour in the automotive industry. When the problem of static equipment cost came up during the discussion, Geisendorfer of Chrysler got up and said that they consider down-time to be worth a \$1,000 a minute on their automotive lines. He pointed out that with this

FREQUENCY STANDARDS



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FREQUENCIES
240-400-500-1,000 cy.

ACCURACIES

Type 50 $\pm 0.02\%$ (-65° to 85°C)
Type R50 $\pm 0.002\%$ (15° to 35°C)

TYPE
50

Requires double triode and
5 pigtail components

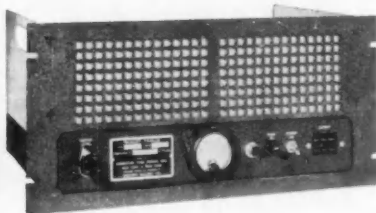
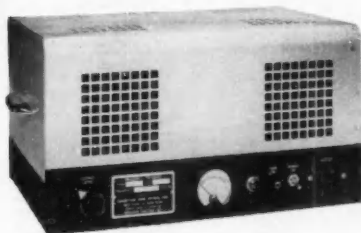
Size, 1" diameter x $3\frac{3}{4}$ " high
Weight, 3.5 ounces

POWER

75 Watt

FREQUENCY STANDARD

TYPE 2111C



FREQUENCIES:50 to 1,000 cycles

ACCURACY: .. $\pm 0.002\%$ ($+15^{\circ}$ to $+35^{\circ}\text{C}$)

OUTPUT:115V, 75 Watts

INPUT:110V, 50 to 75 cycles

SIZE: with cover...10"x17"x9" high

PANEL model,..10"x19"x8 $\frac{3}{4}$ " high

WEIGHT:25 pounds

This organization makes frequency standards within a range of 30 to 30,000 cycles. They are used extensively by aviation, industry, government, (armed forces) where maximum accuracy and durability are required.

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FREQUENCY STANDARD

TYPE 50L

FREQUENCIES

50-60-75 or 100 cy.

ACCURACIES

TYPE 50L

$\pm 0.02\%$ (-65° to 85°C)

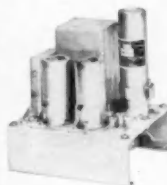
TYPE R50L

$\pm 0.002\%$ (15° to 35°C)

INPUT: 150 to 300V, B (6 V at .6 amps.)

OUTPUT:2V into 200,000 ohms.

SIZE:.. $.3\frac{3}{4}$ "x4 $\frac{1}{2}$ "x5 $\frac{1}{2}$ " high. Wgt., 2 lbs.



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Gentlemen: Please send details on your Type.....

Name.....

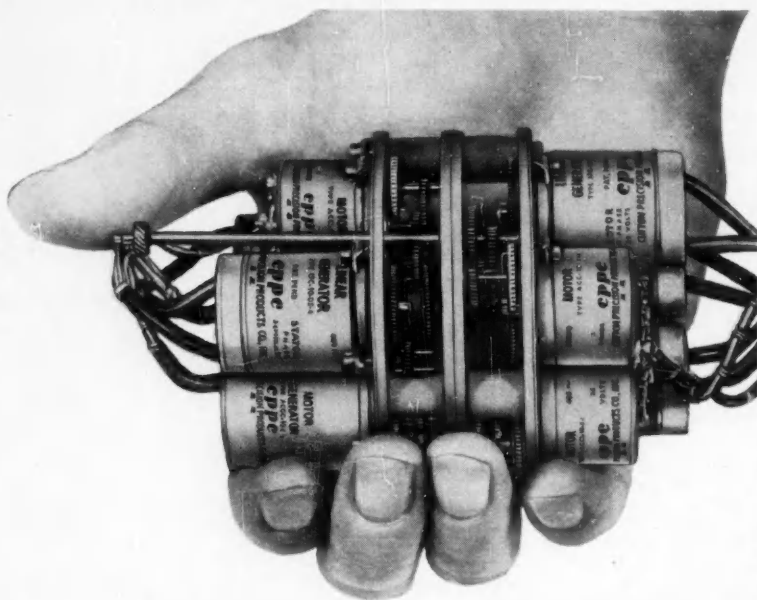
Company.....

Address.....

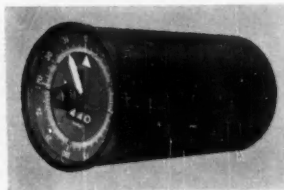
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4 Intercoupled servo loops

WHAT'S NEW



weight less than 2 lbs.*



This indicator, part of an Automatic Navigational System, contains 6 synchros, 2 motors and 2 motor generators—all Clifton Size 10 units.

These units (and 2 mechanical differentials) are built into 4 independent, intercoupled servo loops. Weight of these 4 loops plus gears and gear plates is less than 2 lbs.

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Clifton Heights, Pa.

high cost of down-time anything that would improve reliability or reduce down-time through ease of maintenance would be welcome. He claimed satisfaction in his experiences with static switching devices, and stated that Chrysler had no problems in system redesign.

► Fisher of Allen-Bradley stated that he had heard that static switching components often are not interchangeable. This comment was immediately refuted by Weathers of Westinghouse and other manufacturers and users.

► Krause of Brown & Sharp commented on the indicating lines GE includes on each of its logic elements. He observed that if the equipment is supposed to be so reliable there might be more of a problem in replacing line than in maintaining equipment. However, Weathers mentioned that these were neon lines with long life make and that they would have the advantage of visually showing machine sequence.

"The general tenor of the whole discussion period seemed to be that the machine tool industry is anxious to obtain this equipment, but is not completely satisfied with what is now available—particularly the large, costly, and inaccurate proximity switches."

Grabbe Reports on TIMS

Writes Consulting Editor Dr. Eugene Grabbe, "Some 350 people from engineering and management attended the Third Annual Meeting of The Institute of Management Sciences in Los Angeles last Oct. 18-19. Of specific interest to control engineers was the first session—devoted to 'Management Science and Automation' (Ed. note: Gene chairmanned this session.) D. W. Lynch of GE, dealing with the 'Impact of Automation on Management', told how a computer in his plant reduced a normal 14-week design period to three days. Next, B. A. Willsey of Solar Aircraft revealed that 'automation studies' are now an integral part of his company's production plans for aircraft parts. F. Carlin of Lockheed followed with facts on a similar digital approach to parts production planning—in this case output was increased from 135,000 to 290,000 parts per week. F. G. Steele of Litton Industries closed the session with a report on the company's new low-cost, 12-tube inventory control computer."

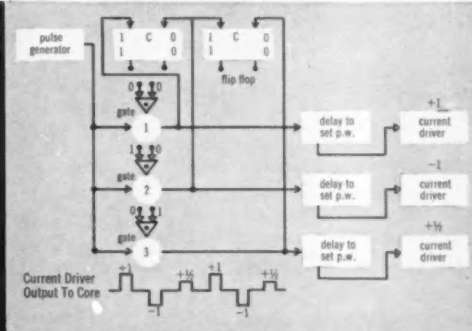
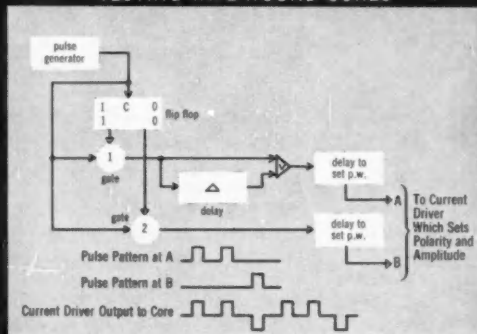
modern methods for testing cores

The future of magnetic cores in information handling systems is already well assured. Their high reliability, fast action, small size, and low power consumption stimulate the imagination of more and more engineers working in data processing, weapons systems, and control. And every day finds these new components included in more new designs.

One problem still facing those who want to exploit these exciting properties is the lack of precise uniformity in cores made on a production basis. For as Burroughs has found through 5 years of working with the pioneers in core applications, uncertainties still exist. And before cores become standardized, many changes will probably be made. Those who want to take advantage of the great potential in this new component now must use reliable test procedures which precisely check the tolerances of each core, and are versatile enough to check for the new core specifications of tomorrow.

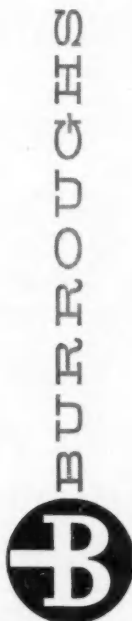
Burroughs Pulse Control Systems answer this need for leading manufacturers and users of cores by simulating the actual conditions under which each core produced will eventually operate. When conditions require a change in core operating characteristics, the testing system is changed at will, in a matter of minutes, to meet the new requirements.

TESTING TAPE-WOUND CORES

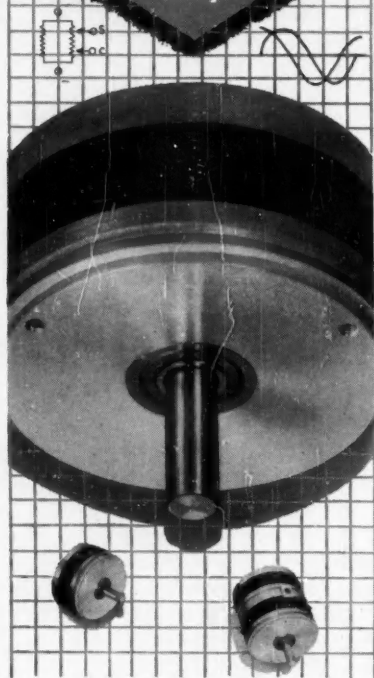


TESTING FERRITE CORES

Shown here are typical examples of how these core manufacturers, including Burroughs own core production department, use Burroughs Pulse Control Systems to check tape wound and ferrite cores. An interesting booklet describing core testing in greater detail is yours for the asking. But if you want to test another component by digital techniques, just send us your problem. We'll be glad to work it out, at no cost, and show you how Burroughs Pulse Control Systems can save you hours of engineering time and production headaches.



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WHAT'S NEW



DATA LOGGING TOPICS: Above Art Freilich of Burrughs responds to a question on computer control from the audience. On the right Harry Moore of Esso tells an intent audience about his experience with three logging systems.



(Continued from page 21)

"Phil Gilman of Taylor Instrument Cos. brought the session right down to earth on costs. He compared the cost of an automatic data logger to the cost of an equivalent graphic panel for supervising the same small 100-point process. At about \$350 per point (including all transducers and totalizers) the logger for this plant would cost \$35,000—about 20 percent more than the cost of an equivalent graphic panel. He estimated that the logger would save \$1,000 a year alone by removing the need for chart planimetry, and that it would save \$3,000 yearly through accuracy and efficiency. His pay-off point: with other corrective savings and some intangibles the average data logger could earn its own keep within two years.

"Gilman reported on an interesting survey on data logging by the M. W. Kellogg Co. By 1960, estimated Kellogg, \$8 million worth of data loggers will be installed in the chemical and petroleum field, as against \$21 million for graphic panels. By '65, the logger sales will total \$18 million, while the graphic sales will have crept up to \$29 million.

"As the maker engineers spoke and asked questions about data loggers I gained an interesting insight into the general outlook of this group. While competition for the first few installations is fierce between the dozen or so makers, there is also a camaraderie between the contestants. The problem now, they seem to say, is not whose system will be bought, but, getting some system sold. They feel they first must sell the concept of data logging before they can sell their own system. Hence the makers—at this session at least—put up a rather united, enthusiastic front as they parried the rather discerning questions from the users.

"Intense quiet prevailed during user reports on their data logging installations. Harry Moore of Standard Oil of New Jersey covered the facts directly and succinctly. 'We have experience with three units', he said. 'One is working fine, another half-fine, and the third is a complete failure.' He also indicated that a forth logger is about to go in, and that four additional units are practically on order.

"Moore ran down the problems. Stepping switches, he said, have been very troublesome. There is not enough self-checking in the system. Maintenance, however, has not been too much of a problem in 'the systems that work'. The quality of workmanship varies greatly in the three different systems. Moore felt that a 100-point installation was a good starting point for a logger. He was complementary about the integrating function that loggers provide—'now for the first time we have a good honest-to-gosh integrator'. He didn't see standardization as a major problem right now, but said it would become one when 10, 12, even up to 20 automatic data loggers are in one refinery.

"Harry Moore sees major application for loggers in tank farms, pilot plants, test stands, and as plant operating guides. He gave out a big-story lead (see next February's CtE): the company is equipping a Cuban refinery with an automatic data reduction system that includes a \$20,000 analog computer to solve fairly complex process equations.

"An unsolicited but revealing testimony on use came during the floor discussion from Walter Bauer of Standard Oil of Ohio. 'We have', said Bauer, 'three loggers installed. The first went in December 1955 on a petro-chemical process. (It was scheduled to start running last month.) The second went onto a pilot plant in

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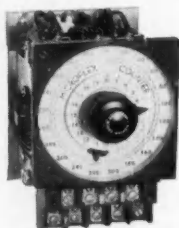
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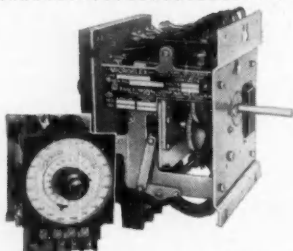


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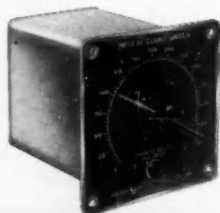
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WHAT'S NEW

February '56. It is working fine, and has a 99-percent service factor. The third recently was hooked up to a catalytic reformer. It worked at start-up, but two or three weeks after the maker's 'expert' left the system went down and have given us trouble ever since.

"Bauer indicated that while he sees very little immediate justification for loggers, he does feel that in-line computing is needed urgently—and that the logger is a means toward this end. He felt that the user must develop its own people to take care of loggers and that the biggest lack is in the area of proper analytical instruments to bring in the right kind of information for logging systems

A look ahead

"The need ultimately for computing equipment in the data reduction system—so strongly suggested by Bauer—was brought out in detail by Art Freilich of the Burroughs Corp. Freilich drew a picture of how a small central computer could be brought into the control loop and into the data logging system. Such a computer, he said, would only up the cost of a 50,000-point logging installation by roughly 2 percent. The computer would perform process calculation like the one below:

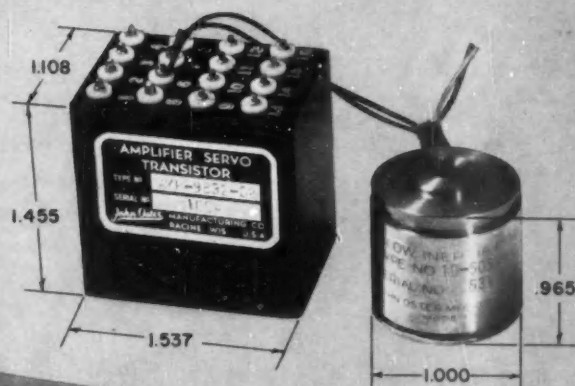
$$\text{Efficiency} = \frac{\text{heat flow} \times (T_{\text{out}} - T_{\text{in}}) \times k \times 100}{\text{fuel flow} \times \text{heating value}}$$

This efficiency calculation, with all auxiliary computations, would take the computer only $\frac{1}{2}$ sec. But, warned Freilich with unusual frankness, today's computers are still not reliable enough for on-line process control service. He suggested that this problem will soon be solved through solid-state devices such as bistable magnetic cores as logic elements.

"One of the final speakers was Paul Knaplund of IBM, who disclosed in his 'look ahead' talk that his company is jumping with both feet into the industrial process control field, using, of course, its stockpile of digital data reduction and computing techniques. He suggested that 'perhaps the loggers of the future will display data like a graphic panel displays information'—in other words, not in columns, but in a form more easily comprehended by the operator. He predicted that there will be two computers working together in the process plant—1) the process logging and control computer, and 2) the business data processor—and that then two loops will ultimately intertwine."

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- Power Output: 0.5 watt minimum.
- Power Requirements:
 - + 19.5 Vdc—250 ma.
 - + 4.5 Vdc—20 ma.
 - + 8.5 Vdc—6 ma. (regulated $\pm 5\%$)
- Amplifier Rating: 0.5 watt min. at 25°C.
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SERVO MOTOR DATA

- With .015V at 400 cycles applied to amplifier input, motor pinion rotates 5000 RPM minimum under no load conditions.
- With .075V at 400 cycles applied, motor develops .15oz.-in. minimum stall torque. Minimum speed 6200 RPM under no load conditions.
- Up to 0.2 oz.-in. torque can be obtained by energizing the reference phase with 31.0V if motor has an adequate heat sink. This results in a reference phase current of approx. .210 amperes.

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WHAT'S NEW

More on Heidelberg:

by TOM GOODMAN of MIT

With a Fulbright scholarship and a Guggenheim fellowship tucked into his brief case, Thomas P. Goodman, assistant professor of mechanical engineering at MIT, took off recently on a sabbatical to Europe. In the following dispatch written expressly for CONTROL ENGINEERING from Munich, Tom discusses the Russian contribution to the Heidelberg control conference (CtE, Dec. '56, p. 32) and reports on conversations with delegates from several satellite countries. The dispatch can be read as an interesting commentary in itself, or as an introduction to a special report on the "state of the art" of statistical techniques in control, which Tom is shaping for CtE out of Heidelberg papers by Russians, Germans, and Americans. Note that throughout there is no attempt to mitigate the technological competence reflected in the Russian papers.

"The Institute of Automatics and Telemechanics in Moscow was represented at the recent International Conference on Control Technology in Heidelberg by four delegates, whose six papers gave American control engineers an opportunity to obtain first-hand information about the activities of this division of the Soviet Academy of Sciences. The institute has a large staff of professors (most of whom have no teaching duties) and research engineers, and is devoted primarily to pure research on problems of automatic control. It also publishes the journal *Automatics and Telemechanics*.

"Prof. Alexander M. Letov, a specialist on nonlinear systems and editor of *Automatics and Telemechanics*, headed the institute's delegation at the conference. Others were Prof. Yakov Z. Tsypkin, Russia's top man on pulse-data systems; Boris N. Naumov, a specialist on numerical computation; and V. A. Racheyev, a specialist on statistical methods. Although nothing was said officially about the overall research program of the institute, the papers presented and the discussions of other papers by the Soviet delegation gave an indication of the range of research which it encompasses.

"Papers presented described the development of large-scale electronic

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and industry"

WHEN YOU SPECIFY POWER SUPPLIES

... you are entitled to all of the benefits of complete facilities, thoroughly experienced engineers, wide product range, prompt delivery and competitive prices.

WHY SETTLE FOR LESS?

Take a standard DC requirement, anywhere between 6 and 1000 volts. You need a good, reliable standard DC source — you want to be able to install it and forget it. You want it promptly and, since it's a standard item, you want it for a reasonable price.

If you investigate Sorensen's "Nobatron" group — more than 70 models available "off the shelf" — and look a bit deeper than the electrical and mechanical specs, here's what you'll find:

*Reg. U.S. Pat. Off. (NO BATTERIES — ELECTRONIC CONTROL)

THE OUTSIDE APPEARANCE —



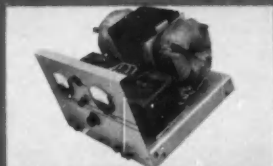
clean, functional, careful attention to small details. Not always vital, but indicators of quality design, workmanship, and materials.

IF WE CAN MAKE A COMPONENT BETTER, WE DO.



If somebody else can do it better, more economically and faster — like we make power supplies — we buy it. Either way, it means better quality for you.

INSIDE, TOP QUALITY COMPONENTS —



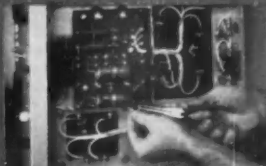
rugged construction — sound engineering proved by tens of thousands of successful units.

THE ACCUMULATED EXPERIENCE OF SORENSEN'S ENGINEERING STAFF —



specializing in power control — is more than 215 man-years. That means less "second guessing," less engineering time, faster delivery, lower cost. And better units.

NEAT, UNCLUTTERED WIRING —



firm, long lasting connections — hallmarks of skilled people. You don't learn this workmanship overnight, but it's the key to a reputation for precision.

OUR SALES ENGINEERING STAFF AND MANUFACTURERS REPRESENTATIVES



work together to put all of these facilities, all of this experience, at your immediate disposal. All it takes is a phone call.

In short, don't just buy "a power supply." Whether it's a precision regulated source for a special job, or a standard low cost unit, start with Sorensen ...



SORENSEN & COMPANY, INC.

375 FAIRFIELD AVE. • STAMFORD, CONN.

In Europe, contact Sorensen-Ardag, Eichstrasse 29, Zurich, Switzerland, for all products including 50 cycle, 220 volt equipment.

Plug in New System Designs!

You can modify parameters to form a new control system design by simply changing the external patch cord connections of the Servomation® Building Blocks.



20-20 Jericho Tpke. New Hyde Park, L.I., N.Y.

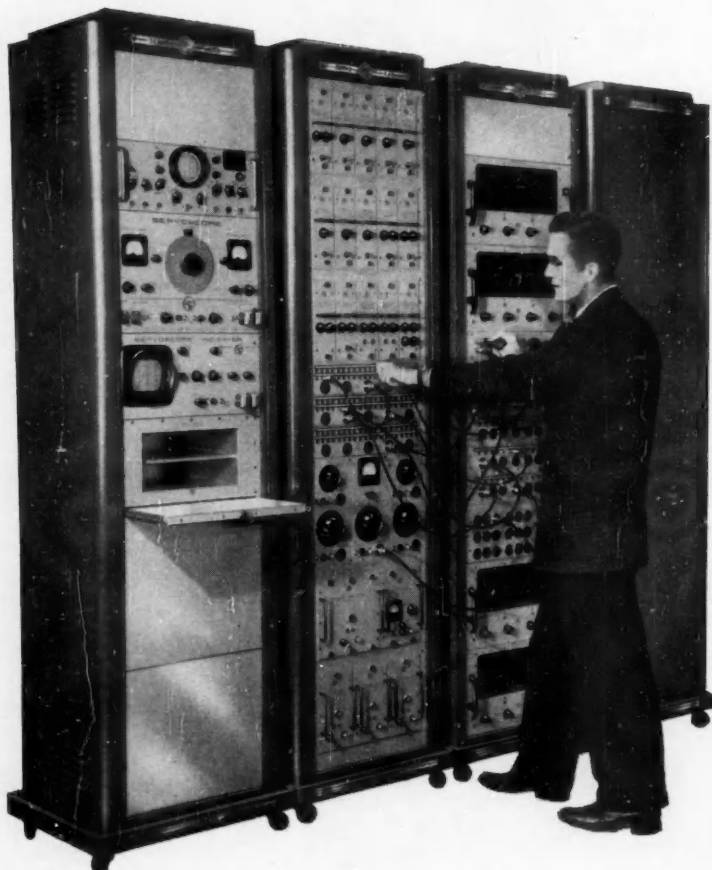
The variables that affect the behavior of your new system under operating conditions can be quickly and conveniently simulated. Environmental and life tests of your new system can be performed at the same time with the Servomation Building Blocks to prove out your design in its final form.

It's as fast and as easy as that. You have a complete simulating and check-out laboratory for an *unlimited* number of different control system designs. Servosystems ranging from complex navigational problems to simple mechanical linkage ratios can be set up and analyzed without time-consuming programming or highly-trained operators.

Suitable for immediate use regardless of problem complexity, the Servomation Building Blocks offer rapid debugging and check-out of complete industrial, aircraft and missile systems.

Free! New Servomation Building Block Catalog

Fully illustrated, gives a complete description of the Building Block equipment plus detailed applications to specific design problems. Please specify on your company letterhead SBB-9904-56A.



WHAT'S NEW

analog computers in the U.S.S.R.; a theoretical method of investigating the structural stability of linear systems; a theoretical method of investigating the stability of a system containing a non-linearity; synthesis of pulse-data systems for automatic control; a numerical step-by-step method for computing the output of a nonlinear system; and a general theoretical approach to the design of self-optimizing systems. In none of the papers was there any mention of the practical applications to which these methods and devices are being put; in Letov's paper on the stability of nonlinear systems, however, there is one broad hint: the system considered as an example is said to be a generalization of a system previously considered by Oppelt in an article on the control of an aircraft in flight.

"The practice by Russians of citing only Russian references has changed—copious references were made to non-Russian work in several of the papers. Tsyarkin, in the oral presentation of his paper, went out of his way to give credit to the work of men outside Russia in the field of pulse-data systems. At the closing banquet of the conference, Letov said that the Russian delegates would do their best to further international cooperation in the field of automatic controls.

"Conversations with delegates from satellite countries revealed that the Institute of Automatics and Telemechanics, and Soviet scientific research generally, are held in high esteem throughout these countries. In Poland and Czechoslovakia there are national academies of sciences whose organization is patterned after that of the Soviet Academy of Sciences. In Poland, the top graduate of the Technical University in Warsaw each year has the privilege of going to Moscow to study for a doctorate.

"Soviet books and articles on automatic controls are in wide circulation in the satellite countries. Their wider use in Western countries, however, is thwarted by two barriers: the first is language, the second the fact that Soviet authors almost universally avoid the use of transfer functions and block diagrams. Instead, they describe systems in terms of differential equations. Thus, in Russian articles, ideas which would be readily intelligible to American readers if expressed in conventional transfer-function or block-diagram form become obscured by unfamiliar notation."

Compact power relay— high contact ratings

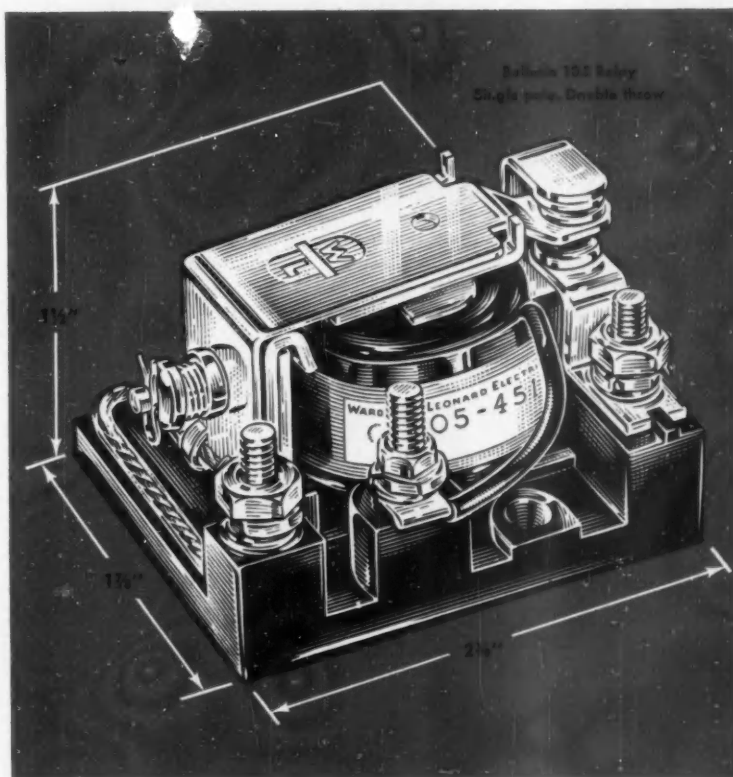
More relay for your money—that's the big thing you get when you specify Ward Leonard's Bulletin 105 for light power switching jobs.

No delicate, misapplied telephone- or instrument-type relay, the 105. From rigid phenolic base to ample silver-to-silver, self-cleaning contacts, the 105 is built to deal with *power* . . . just like the larger Ward Leonard relays and contactors. And yet it's extremely compact and low in cost.

You'll find the Bulletin 105 relay—in SPST, SPDT, DPST, and DPDT types—ideal for controlling power to electric heaters, signals, pumps, radio and tv transmitters and public address systems.

Check your catalog file today for Bulletin 105. If it's missing write to: Ward Leonard Electric Co., 9 South Street, Mount Vernon, N. Y. (In Canada: Ward Leonard of Canada Ltd., Toronto.)

7.1



ENGINEERING DATA

SINGLE POLE BULLETIN 105 RELAY

Contact Ratings

Volts	D.C. Amps.*		A.C. Amps.*	
	N.O.	N.C.	N.O.	N.C.
0-24	20	15	20	15
25-125	1/2	1/2	20	15
126-250	—	—	15	10

*Ratings are non-inductive.

COIL VOLTS: 6, 8, 10, 12, 24, 32, 48, 115, 230

AVG. COIL WATTS: 2 D.C., 3.75 A.C.

PICK-UP: 85% or less of rated voltage

WEIGHT: 5 ounces

TERMINALS: Stud type

LIVE BETTER...Electrically

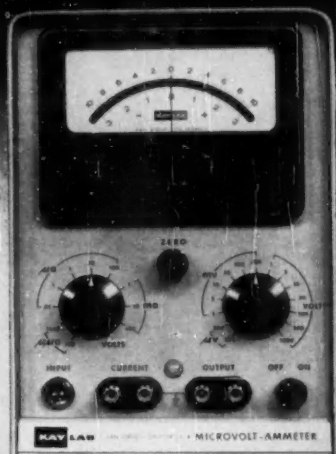


**WARD LEONARD
ELECTRIC COMPANY**
MOUNT VERNON, NEW YORK



Relay—Engineered Controls Since 1912

**SUCCESSOR
TO VTVM**
measure amplify
uv...ma



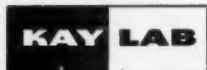
Universal DC Meter

This new microvolt-ammeter-amplifier will measure as little as $10 \mu\text{v}$ or $10 \mu\text{a}$ with accuracy. It may also be used as a DC amplifier with up to 80 db gain and only $10 \mu\text{v}$ drift. A zero-center mirrored scale provides instant polarity indication. Utilization of Kay Lab's chopper stabilized circuit provides versatility, accuracy, and stability that is unobtainable with conventional VTVM's. The Model 203 is the ideal general purpose laboratory meter, production test set, or null meter.

SPECIFICATIONS

- $100 \mu\text{v}$ to 1000 v fs
- $100 \mu\text{a}$ to 100 ma fs
- 25 ranges
- 100 megohms input
- 80 db gain as amplifier
- $10 \mu\text{v}$ equivalent input drift
- 1 volt output
- Price \$550.

*Representatives in all major cities
Write for literature or demonstration*



5725 KEARNY VILLA ROAD
SAN DIEGO 11, CALIFORNIA

WHAT'S NEW

**All Around the
Business Loop**

► The advent of the computational center, serving companies that do not have their own computers, has so impressed people in and out of the control field that chances are many of them overlook the fact that a center, like any other business, is a money-making enterprise. Perhaps **Electronic Associates, Inc.**, which recently opened its second analog computational center—this one in Los Angeles—has been aware of this, for a statement announcing completion of the project contains specific dollars-and-cents figures pertaining to each service offered.

Thus, rental of either one of two computers, each the heart of a Pace analog computing system, is at the rate of \$45 an hour, rental of both is \$90. An electronic multiplier rack hires out for \$8 an hour, a two-pen, 30-by-30 in. X-Y plotter for \$5.25. Built into each system are 80 potentiometers, 60 amplifiers, 10 multiplying servos, each with five multiplying cups, eight pot padders, three resolvers, four diode function generators, a 10-by-17-in. X-Y plotter, a six-channel recorder, a digital voltmeter, and a noise generator. Customers using both computers get service of the big X-Y plotter free.

EAI claims several "firsts" for its new center. The physical layout, for example, is said to be the first designed specifically for this kind of undertaking. Inside there are other innovations: tape print-out of the voltages appearing at the output of all

the amplifiers, multipliers, resolvers, diode function generators, and some of the pots and trunk lines; a problem-check for reading the value of the derivatives of all the integrators. Cost of all the equipment, if any company were to make this kind of investment, says EAI, would be \$200,000.

Lloyd F. Christianson, president of EAI, and William Kindel, director of the new center, joined in making the announcement. Christianson credited EAI's first center, at Princeton, N. J., for much of the knowledge to be put to work in Los Angeles. Touching on EAI business, he said sales in 1948, three years after the company got started, amounted to \$466,000, and seven years later, in 1955, totaled \$7 million. Six-sevenths of the latter figure, Christianson continued, had been racked up by mid-1956, despite the fact that EAI has been deliberately cutting down on government contracts.

► At about the same time comes news of IBM's gift of a 705 electronic data processing machine to UCLA, to be housed in its own research building, to which the company will contribute half the cost. Called by turn the world's first university computer center and the **Western Data Processing Center**, the project is the most impressive IBM present to-date to educational institutions. It follows close upon a gift of a 704 data processor to MIT, which is cooperating with at least 23 other New England colleges in a move to increase the number of qualified users of large-scale computers and to learn more about these

(Continued on page 166)



BUSINESS AS USUAL—Here's the man we've often talked about but never really met: the one who works while the building falls down around him. If he represents the kind of manpower on Concord Control's payroll, the company has nothing to worry about. The picture appeared on a CC post card informing customers that the company has a new building and a new address. Cute, huh?



A major step forward has been achieved by uniting Fairchild precision potentiometers with dynamically balanced and sensitive pressure-sensing elements. The result is a line of superior pressure transducers with potentiometer outputs and featuring all the characteristics of precision, reliability and quality that are identified with Fairchild potentiometers. A specially trained staff of engineers is at your service to consider problems of transducer design and manufacture to meet your specific requirements.



MINIATURE PRESSURE TRANSDUCERS

**Featuring Fairchild
accuracy and reliability**

The TP-200 illustrated is a new and smaller addition to the line of Fairchild Transducers. These components are now available in a wider range of resistances in either linear or functional, single or dual potentiometer output elements. Measuring only approximately 2" by 2", the TP-200 features a single pressure sensitive diaphragm element which actuates one or two precision potentiometers through dynamically-balanced, stable mechanical linkage. It features unitized construction for easy assembly, field calibration and repair. Variations of size, conformation, and pressure ranges for measurement of differential, absolute, or gauge pressures are available. For complete information write Fairchild Controls Corp., Components Division, Dept. 140-77C1.

EAST COAST
225 Park Avenue
Hicksville, L. I., N. Y.

WEST COAST
6111 E. Washington Blvd.
Los Angeles, Calif.

FAIRCHILD
**PRECISION POTENTIOMETERS
and COMPONENTS**



GUIDED MISSILE

RESEARCH and DEVELOPMENT

A major guided missile research and development program has several significant characteristics that are of particular interest to the scientist and engineer.

First, it requires concurrent development work in a number of different technical areas such as guidance and control, aerodynamics, structures, propulsion and warhead. Each of these large areas in turn contains a wide variety of specialized technical activities. As an example, digital computer projects in the guidance and control area involve logical design, circuit design, programming, data conversion and handling, component and system reliability, input-output design, and environmental and mechanical design.

A second characteristic is frequently the requirement for important state-of-the-art advances in several of the technical areas. For instance, the supersonic airframe needed for a new missile may necessitate not only novel theoretical calculations, but also the design and performance of new kinds of experiments.

A third characteristic of missile development work is that such close interrelationships exist among the various technical areas that the entire project must be treated as a single, indivisible entity. For example, what is done in the guidance portion of the system can affect directly what must be done in the propulsion and airframe portions of the system, and vice versa.

These characteristics make it clear why such work must be organized around strong teams of scientists and engineers. Further, for such teams to realize their full potential, they must be headed by competent scientists and engineers to provide the proper technical management. And finally, all aspects of the organization and its procedures must be tailored carefully to maximize the effectiveness of the technical people.

Principles such as these have guided The Ramo-Wooldridge Corporation in carrying out its responsibility for overall systems engineering and technical direction for the Air Force Intercontinental and Intermediate Range Ballistic Missiles. These major programs are characterized by their importance to the national welfare and by the high degree of challenge they offer to the qualified engineer and scientist.

*Openings exist for
scientists and engineers
in these fields of
current activity:*

Guided Missile Research and Development
Aerodynamics and Propulsion Systems
Communications Systems
Automation and Data Processing
Digital Computers and Control Systems
Airborne Electronic and Control Systems

The Ramo-Wooldridge Corporation

5730 ARBOR VITAE STREET • LOS ANGELES 45, CALIFORNIA

NOW...from **VICKERS***

a complete line of
STANDARD HIGH GAIN MAGNETIC AMPLIFIERS

...from the pioneers and
developers

**YOUR LARGEST AND
MOST DEPENDABLE SOURCE
4 WEEKS' DELIVERY**

(many can be shipped directly from stock)



BULLETIN NUMBER	AC SUP- PLY	DC POWER OUTPUT (SEE NOTE 3)				DC CON- TROL AMP- TURNS	RESPONSE TIME					POWER GAIN			CONTROL WINDINGS (SEE NOTE 5)				BUL NO.	
		Volts	Watts	DC Volts	DC Amps.		Load Ohms	3 CYCLE 63%		NO EXTERNAL R		SEE NOTE 4		(500 TURN WONG)		WINDING 5-6 100 TURNS		WINDING 7-8 800 TURNS		
								Input Watts	Ohms N ²	Input Watts	Cycles	C ¹	C ²	3- 63%	No Ex- ternal R	Ohms	Max. Amp.	Ohms		Max. Amp.
1 PHASE POWER SOURCE (NOTE 1)	2502	120	3.9	37	.105	350	4	.013	.0011	.0030	13	.0027	.5	290	1200	2.4	0.58	70	0.12	2502
	2503	120	6.7	43	.155	275	4	.023	.0019	.0025	26	.0047	.5	300	2700	2.0	0.58	58	0.12	2503
	2504	120	13	43	.30	145	5	.038	.0015	.0063	46	.0037	.6	340	2050	2.5	0.73	54	0.15	2504
	2505	120	23	46	.50	92	5	.057	.0023	.0060	62	.0055	.6	400	3940	2.4	0.73	66	0.15	2505
	2506	120	47	50	.94	53	5	.098	.0039	.0060	95	.0094	.6	480	7850	2.4	0.73	73	0.15	2506
	2507	120	80	53	1.5	35	7	.125	.0026	.0049	67	.0059	.7	640	16300	1.0	0.92	28	0.18	2507
	2508	120	130	57	2.3	25	7	.17	.0035	.0049	82	.0080	.7	760	26500	1.0	0.92	30	0.18	2508
	2509	120	190	58	3.3	18	8	.24	.0037	.0071	84	.0083	.75	800	26800	1.1	0.92	30	0.18	2509
	2510	120	280	60	4.7	12	8	.33	.0051	.0080	104	.0115	.75	850	35000	1.3	0.92	34	0.18	2510
	3 PHASE POWER SOURCE (NOTE 2)	2522	240	19.5	110	.177	620	5.5	.035	.0015	.0180	6	.0037	.4	520	1080	7.2	0.58	210	0.12
2523		240	35.4	125	.283	440	5.5	.053	.0021	.0150	11	.0055	.4	620	2360	6.0	0.58	175	0.12	2523
2524		240	65	130	.50	260	7	.081	.0016	.0415	18	.0041	.5	830	1560	8.5	0.73	180	0.14	2524
2525		240	125	135	.93	145	7	.14	.0028	.038	26	.0068	.5	900	3300	7.8	0.73	220	0.14	2525
2526		240	237	142	1.67	85	7	.22	.0045	.0415	38	.0112	.5	1100	5700	8.5	0.73	230	0.14	2526
2527		240	355	165	2.15	77	8.5	.27	.0038	.0225	35	.009	.6	1300	15750	3.1	0.92	90	0.18	2527
2528		240	550	173	3.19	54	8.5	.37	.0051	.0215	42	.0123	.6	1500	25500	3.0	0.92	90	0.18	2528
2529		240	770	176	4.37	40	10	.48	.0048	.030	38	.0111	.7	1600	25800	3.3	0.92	90	0.18	2529
2530		240	1170	180	6.53	28	10	.60	.0060	.030	42	.0139	.7	1800	39000	3.9	0.92	105	0.18	2530

1. Type DD1B amplifiers (Bulletin Numbers 2502-2510) operate from a 60 cycle, 1 phase power source, and consist of 1 reactor, 2 saturating rectifiers, and 1 complementary rectifier. (See Note 6.)
2. Type DD3B amplifiers (Bulletin Numbers 2522-2530) operate from a 60 cycle, 3 phase power source, and consist of 3 reactors and 6 saturating rectifiers.
3. Basis of Ratings—
Reactor—50° C temp. rise above a 40° C ambient
Rectifier—40° C temp. rise above a 35° C ambient

4. The time constant for any value of resistance in the control circuits can be determined as follows:

$$TC \text{ (in cycles)} = C_1 \frac{N^2}{R} + C_2$$

5. Additional or special control windings can be supplied. Bulletin Numbers 2502, 2503, 2522, and 2523 require special terminal brackets for more than 3 windings. Other 2500 Series amplifiers require special terminal brackets for more than 4 windings.
6. DD1B amplifiers can be supplied as AD1 (AC output) amplifiers. Current and voltage outputs (RMS) are approximately 1.3 times, and AC power is approximately 1.7 times, DC values shown above.

• Other Output and Supply Voltages Available.

• Standard low input amplifiers (10⁻⁹ watts) and standard high output amplifiers (4.5 x 10⁶ watts) are also available. Write today for complete information.

*TRADEMARK

ENGINEERS: There are openings in our expanding program. Write for details.



VICKERS ELECTRIC DIVISION

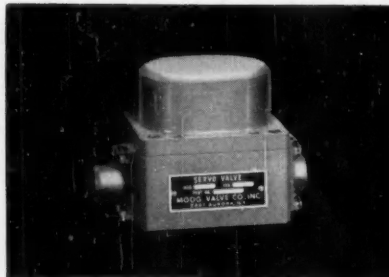
VICKERS INCORPORATED a unit of Sperry Rand Corporation
1805 LOCUST STREET • SAINT LOUIS 3, MISSOURI

From MOOG... **Advanced Electro-Hydraulic Servo Components**

Moog is the industry's leading producer of electro-hydraulic servo valves. This leadership has been achieved by advanced valve design resulting in high performance, high quality, reliability and efficient manufacture. The same creative approach applied to industry's newer

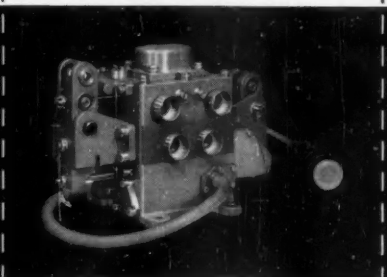
problems has resulted in the introduction of Moog Dual Input and Servo Actuator units.

These recent achievements in the creation of advanced custom designed electro-hydraulic servo components are evidence of Moog's continuing progress.



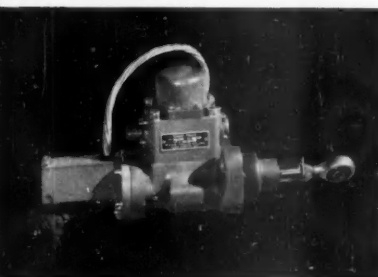
SERVO VALVE

- These proportional "dry motor" electro-hydraulic servo valves feature high dynamic response, sensitivity, linearity and reliability. Light-weight and compact, they are also available in custom designed versions for special or advanced applications.



DUAL INPUT SERVO VALVE

- This new component provides for positioning of aircraft control surfaces by summing mechanical and electrical inputs without external use of mechanical linkages. Use of an entirely new concept offers improved performance, system simplification and saving of space and weight.



SERVO ACTUATOR UNIT

- Custom designed integrated assemblies include actuating cylinder, electro-hydraulic servo valve and feedback sensing device. In a closed loop, actuator displacement is a function of input signal.

TO THE ENGINEER IN A "HURRY"

Axiomatically, to get somewhere in a hurry, you get aboard something that moves pretty fast.

If your "somewhere" is a career in engineering, consider Moog. From three founders to five hundred employees within five years, we are today the industry's leading manufacturer of advanced electro-hydraulic servo components. Our engineers made this possible by continuous pioneering of the new and successful developments in the field. As our rapid expansion continues, we have many openings at all levels for qualified personnel.

Best time to get aboard is now.

**M
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G**



MOOG VALVE CO., INC. PRONER AIRPORT, EAST AURORA, NEW YORK

Research Laboratory, Paramus, New Jersey

HETHERINGTON

SWITCHES • INDICATOR LIGHTS • SPECIAL ASSEMBLIES

ENGINEERING NEWS #2

Space-Saver Toggle Gives Big Switch Performance



When it comes to making a *real* saving in space, this new SP-DT Hetherington Toggle Switch is the answer. It is only $\frac{1}{32}$ " in diameter by $1\frac{1}{32}$ " long. It weighs less than $\frac{1}{4}$ oz. Yet it breaks 5 amp. resistive loads at 28 volts dc ($2\frac{1}{2}$ amps @ 115 v ac) for 50,000 operations.

Best of all, Hetherington's tease-proof cam-roller snap-action gives the T3103 the "feel" of a real heavy-duty switch. Details are in Data Sheet S-3a.

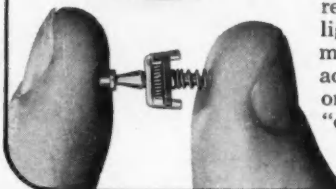
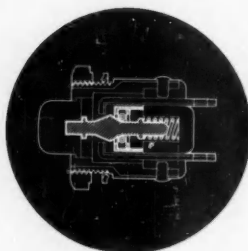
The Switch Design That Says

"NO FOOLIN"

No Tease . . . No Deceptive Clicks

Higher ratings in smaller, lighter-weight switches are made possible by this little beryllium device . . . the heart of every Hetherington snap-action switch.

A polished tapered rod operates through two compression springs in the shorting bar and against the return spring. Its lightning-fast, double-break snap action reduces arcing and contact welding to negligible proportions—even with high momentary overloads. Contact pressure is actually greatest at the point of "make" or "break" thus preventing deceptive "clicks" or contact teasing.

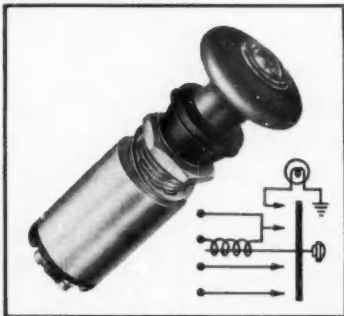


Relay, Switch, and Pilot Light Functions in One Unit Only $\frac{1}{16}$ " x $3\frac{1}{16}$ "

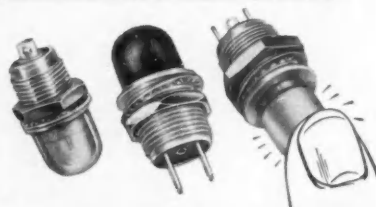
This "control engineer's delight" does the work of *two* conventional switches plus a holding relay and an indicator light. All of this is accomplished in only a fraction of the space, weight, and wiring needed for separate components.

Once the button is pressed, a built-in 28-volt solenoid holds the switch on contact until either the coil circuit is externally interrupted or the button is pulled out. A built-in indicator light shows when the coil circuit is energized.

Modifications of this basic Hetherington Holding Coil Switch design include a variety of circuit arrangements. Pull-on and push-on pushbutton types as well as a toggle type are available. Their many aviation and industrial uses center



around jobs where the switch is manually "closed" to start an operation; then electrically "opened" at the end of the sequence. In an emergency, the switch may be manually opened in the middle of the sequence if desired.



W-I-D-E Angle Visibility from Indicator Lights only $1\frac{1}{4}$ " Long

Almost 50 percent of the surface of these tiny units is useful illuminated area. Thanks to a specially-beveled lens cap, light is "piped" evenly throughout the entire lens. Full 180-degree visibility is assured on either standard or edge-lit panels.

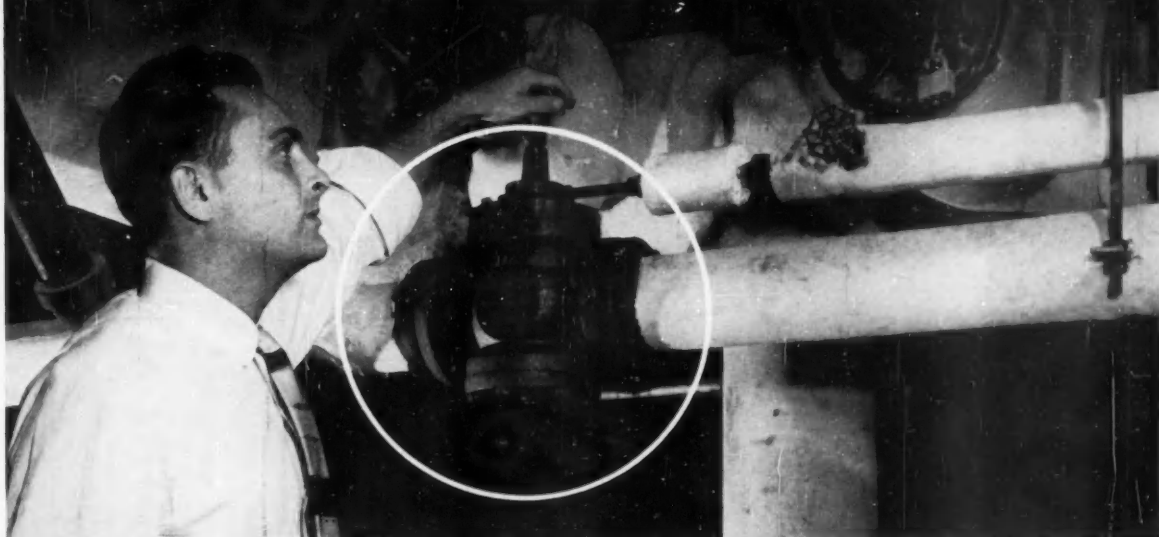
These miniature Hetherington Series L6000 lights come in both 2-terminal ungrounded, or 1-terminal case-ground styles. Single piece terminals and contacts cannot be torn loose by heavy wires. Request Bulletin L-2b.

HETHERINGTON INC. 1200 ELMWOOD AVE., SHARON HILL, PA. • 139 Illinois St., El Segundo, Calif.

Over 455 PRECISION push-button Switch Types

PROVEN PERFORMANCE

at A. E. STALEY Mfg. Co.



CASH STANDARD Type 44

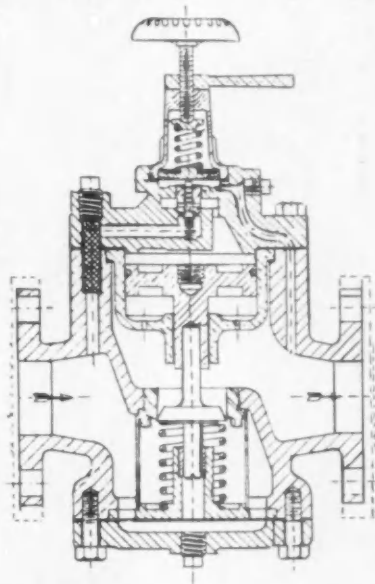
Pressure Reducing and Regulating Valve for Steam Service

Sudden changes in the requirements for hot water in the employees' shower rooms at the Staley plant demand full capacity range operation of the regulating valve with precise control of downstream pressure.

In April of 1956, a CASH STANDARD Type 44 Steam Valve was installed in the line supplying steam to the heater. Gerald Hammond, instrument engineer at Staley, reports: "The CASH STANDARD Type 44 has given exceptionally good service—the kind of service we expect from all CASH STANDARD products. It has required no maintenance since installation eight months ago."

What's your control problem? Use this dependable steam valve.

Built in Pilot and Main Valve Strainers • Internal Pilot-Operated, Piston-Actuated • Single Seat • Highly Sensitive, Responsive to Smallest Changes in Reduced Pressure • Maximum Inlet Pressure 250 PSI @ 400°F. • Delivery Pressure 5-250 PSI • Available with External Sensing Line • Sizes 2", 2½", 3", 4".



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PRESSURE, HYDRAULIC, TEMPERATURE, PROCESS AND COMBUSTION CONTROLS

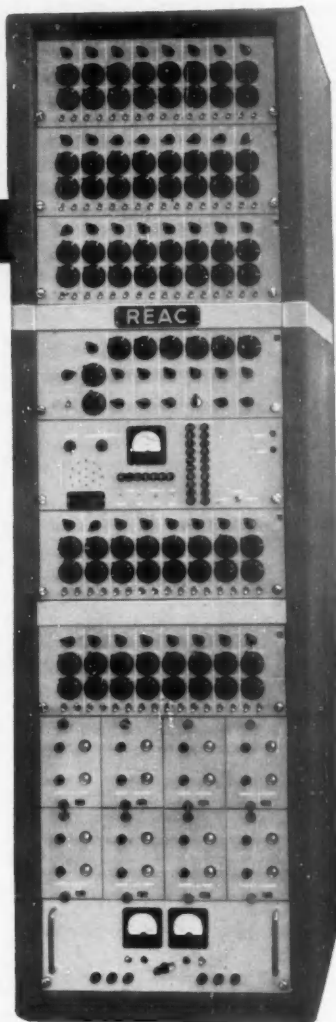
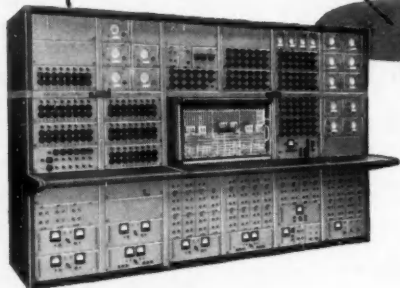
Generation of Functions of *Two or More Variables*

with the

400 series **REAC**®

DIODE FUNCTION GENERATOR

- Allows direct generation of slopes up to 12 volts/volt without paralleling diode segments.
- 10-turn potentiometers for both "slope" and "break point" give excellent resolution. Still further improvement in resolution is obtained by splitting slope adjustment into two ranges.
- 1000-division direct read-out 10-turn dials permit logging of function for fast reproduction later.
- Flexible switching system allows number of segments per channel to be varied from 2 to 30.
- Built-in calibration circuit permits functions to be set up quickly and easily without use of external plotting board.



... a complete self-contained unit

The DFG-401 is a completely self-contained unit consisting of 5 channels of function generation, 15 DC amplifiers (with VTVM and all control circuits for monitoring and balancing), and all necessary power supplies (except relay and reference voltages). In the event that any amplifiers supplied are not needed in the problem, they can be made available in groups at the patchbay as inverters with one gain of one.

This unit is ideal for the addition of up-to-date diode function generation equipment to an existing analog computer installation.

Electronic generation of functions of two or more variables is another outstanding Reeves contribution to the flexibility and efficiency of the electronic analog computer. Before installing new equipment, it will pay you to consult us. A comprehensive new REAC "400" series computer technical brochure will be sent upon request.

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Computers



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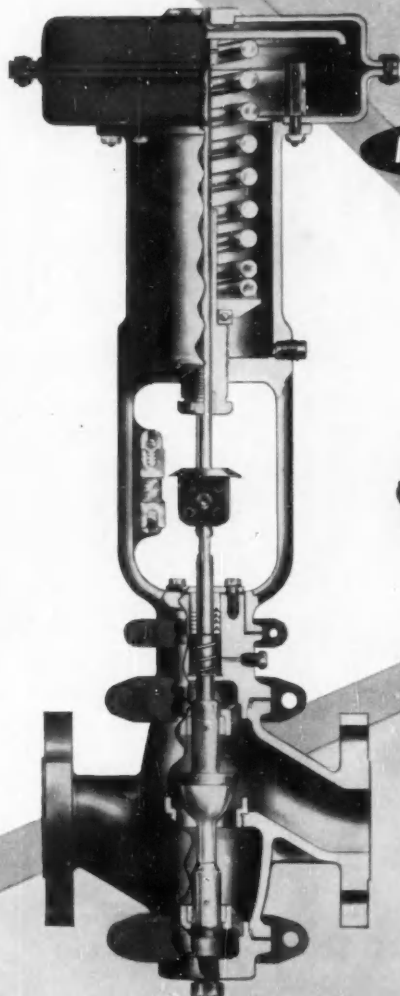
Precision
Resolvers and
Phase Shifters



Servo
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New BS&B Super 70 series TOPWORKS

...Give **FAST,**
ACCURATE Response!



NEW

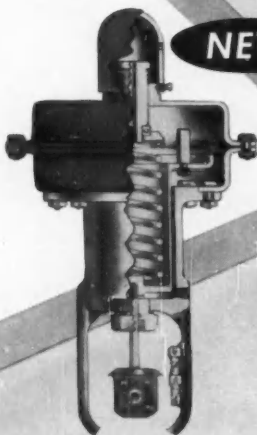
Buna-N moulded diaphragm, reinforced with nylon, gives uniform cross sectional thrust over full valve travel.

NEW

Cadmium plated pressed steel diaphragm cases give maximum strength and corrosion resistance with minimum weight. Special chromate treatment provides superior bonding agent for paint and added corrosion protection.

NEW

Bolted clamp ring device integrates body and topworks assemblies into a single unit, and permits yoke to be oriented to any convenient position for observation and action.



Reverse Type
Topworks

Four sizes of Super 70 Series Topworks are available in both direct and reverse acting types. Both are interchangeable on single port, double port, or split body styles. A single spring, precision calibrated to plus or minus 2% of rating, provides accurate travel response to changes in diaphragm loading pressure. (Reverse type topworks uses recessed spring). Ductile iron yoke provides the rigidity of cast iron and the safety of steel. All units use split and bolted stem connector and adjustable travel scale plate.

This advertisement highlights only features of the Super 70 Series Topworks. For information on the new valve bodies of the Super 70 Series line, ask for Catalog 70-11.

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Controls Division, Dept. 4-ES1

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OIL-IMMERSED SOLENOIDS

give incredible performance



INSTALL THEM AND FORGET
THEM. TESTS SHOW NO
APPRECIABLE WEAR
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Here's why:

SEALED IN OIL. Each unit is sealed in its own, contamination proof, oil filled, die-cast housing. A convenient, plug-in base allows split-second replacement in case of change in power requirements. Heat dissipation and wear control reach a new level of efficiency in these units.

SHOCK MOUNTED. Only DECCO can give you service-proved, two direction shock-mounting—a valuable bonus in the service-life of your solenoids.

BETTER ENGINEERING. Minimum power loss. 30° to 50° cooler operation. Tremendously greater service-life.

DECCO Solenoids are made in a complete range of types, sizes and mountings. AC or DC. SPECIAL SOLENOIDS will be engineered on request.



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0-250 cps
direct-writing
oscillograph



Consolidated Electrodynamics

300 North Sierra Madre Villa, Pasadena, California

NATIONWIDE COMPANY-OWNED SALES & SERVICE OFFICES

WHAT IS IT? A completely new, direct-writing oscillograph/amplifier system for providing an immediate, permanent record of rapidly varying voltages. Its frequency response, portability, flexibility are beyond those of any similar equipment on the market today.

WHAT ARE ITS FEATURES? Excellent square-wave and transient response, and frequency response to 250 cycles. It will record at 1" double amplitude throughout the frequency range of 0 to 250 cycles! The recording system uses no ink . . . traces are clean and easily interpreted. Push-button speed selector provides instantaneous change of the record's time base.

WHERE CAN YOU USE IT? Datagraph can be used to record voltages from many sources . . . e.g., magnetic-tape playback units, carrier amplifiers, audio amplifiers, d-c amplifiers, telemetering discriminators, etc. Its high input impedance adapts it to a myriad of input devices.

WHAT ARE THE SYSTEM SPECIFICATIONS?

FREQUENCY RESPONSE . . . flat $\pm 5\%$ from 0 to 250 cps.

RECORD SPEEDS . . . 0.05, 0.2, 1, 5, 10 and 20"/sec.

NUMBER OF CHANNELS . . . 2

RECORD SIZE . . . 70 mm x 500 ft.

AMPLIFIER INPUT
IMPEDANCE . . . 100,000 ohms

SENSITIVITY . . . 1 inch per volt; 1 inch maximum peak-to-peak amplitude

DIMENSIONS AND WEIGHT:

Oscillograph . . . 9" x 10½" x 17¼",
60 lbs.

Amplifier . . . 9" x 10½" x 17¼",
50 lbs.

WHERE'S THE COMPLETE STORY OF DATAGRAPH?

In a new CEC bulletin, just released. Send for your copy of Bulletin CEC 1569-X8.



IMPORTANT ACHIEVEMENTS AT JPL



The Analytical Mind and Electronic Computers

The Jet Propulsion Laboratory is a stable research and development center located north of Pasadena in the foothills of the San Gabriel mountains. Covering an 80 acre area and employing 1600 people, it is close to attractive residential areas.

The Laboratory is staffed by the California Institute of Technology and develops its many projects in basic research under contract with the U.S. Government.

Opportunities open to qualified engineers of U.S. citizenship. Inquiries now invited.

The Jet Propulsion Laboratory supports its research and development programs with extensive modern digital and analog computing systems. To this end our computer-equipment staff has made important original contributions in the development of new analog computer components, encoding techniques, and digital data handling equipment including advanced systems for handling the high volume output of supersonic wind tunnels.

Though the computing machines have made dramatic contributions to the Laboratory program, the central figures in this

drama remain the applied mathematicians, engineers, and scientists focusing their analytical minds on the problems of their respective technologies and formulating them for computing machine solutions.

Every technology applying to missile propulsion and guidance is represented on the Laboratory: aerodynamics, guidance, instrumentation, electronics, chemistry of propellants, propulsion systems, design and metallurgy. It is in this setting that applied mathematicians and computer engineers find rich opportunities for growth and achievement in scientific computation.

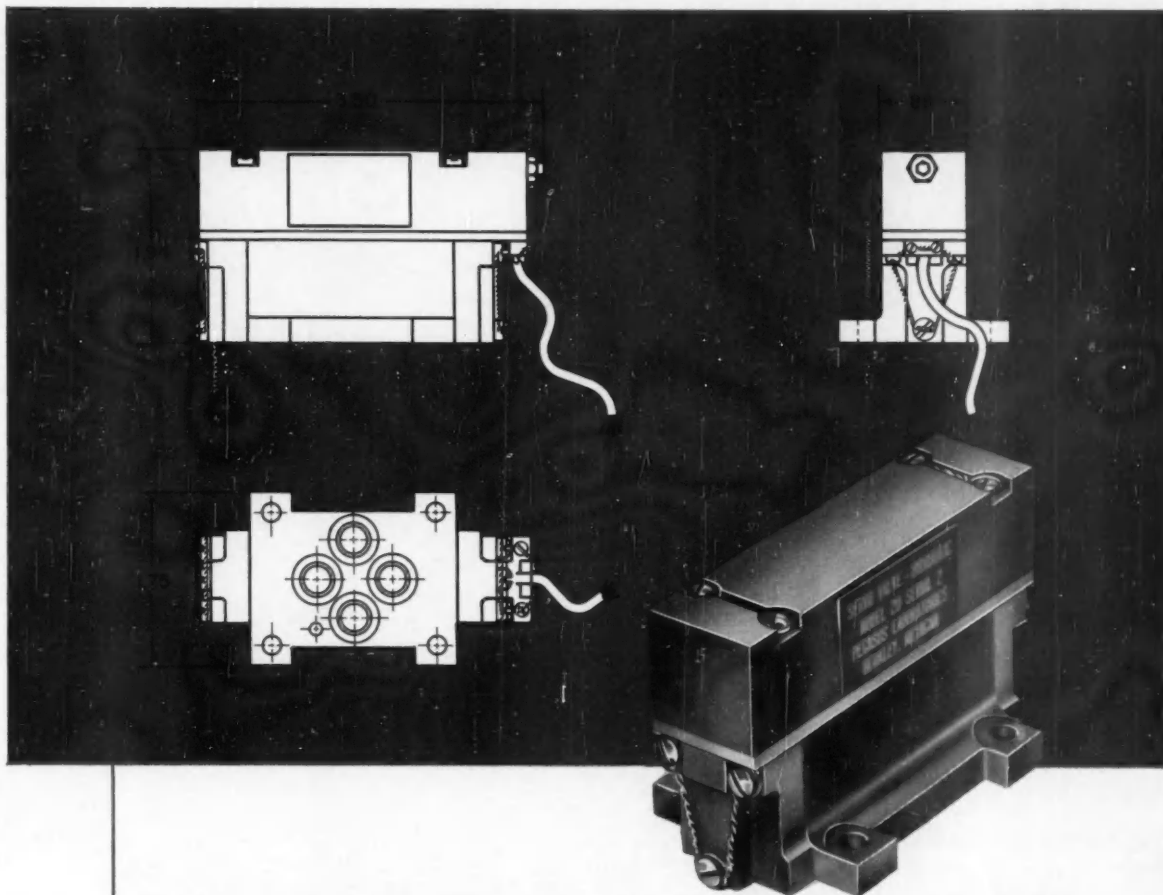
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JET PROPULSION LABORATORY

A DIVISION OF CALIFORNIA INSTITUTE OF TECHNOLOGY
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The PEGASUS Model 20 Servo Valve for Missile and Aircraft Application

IN THE MODEL 20, Pegasus presents a servo valve incorporating the highly reliable, high performance boost technique used in its line of industrial valves, yet meeting the particular requirements of low size and weight, low input power, and high temperature operating range of the aircraft industry.

THE UNIT incorporates high pressure strain barriers to isolate the electrical and magnetic areas of the valve from the hydraulic oil, and uses stainless steel throughout in its construction. The balanced boost drive provides full spool differential pressure for as low as one tenth of the maximum differential current, insuring maximum sensitivity and minimum balance shifts.

WE WOULD BE PLEASED to submit more information, quotations to your specifications, or prototypes of this unit upon your request.

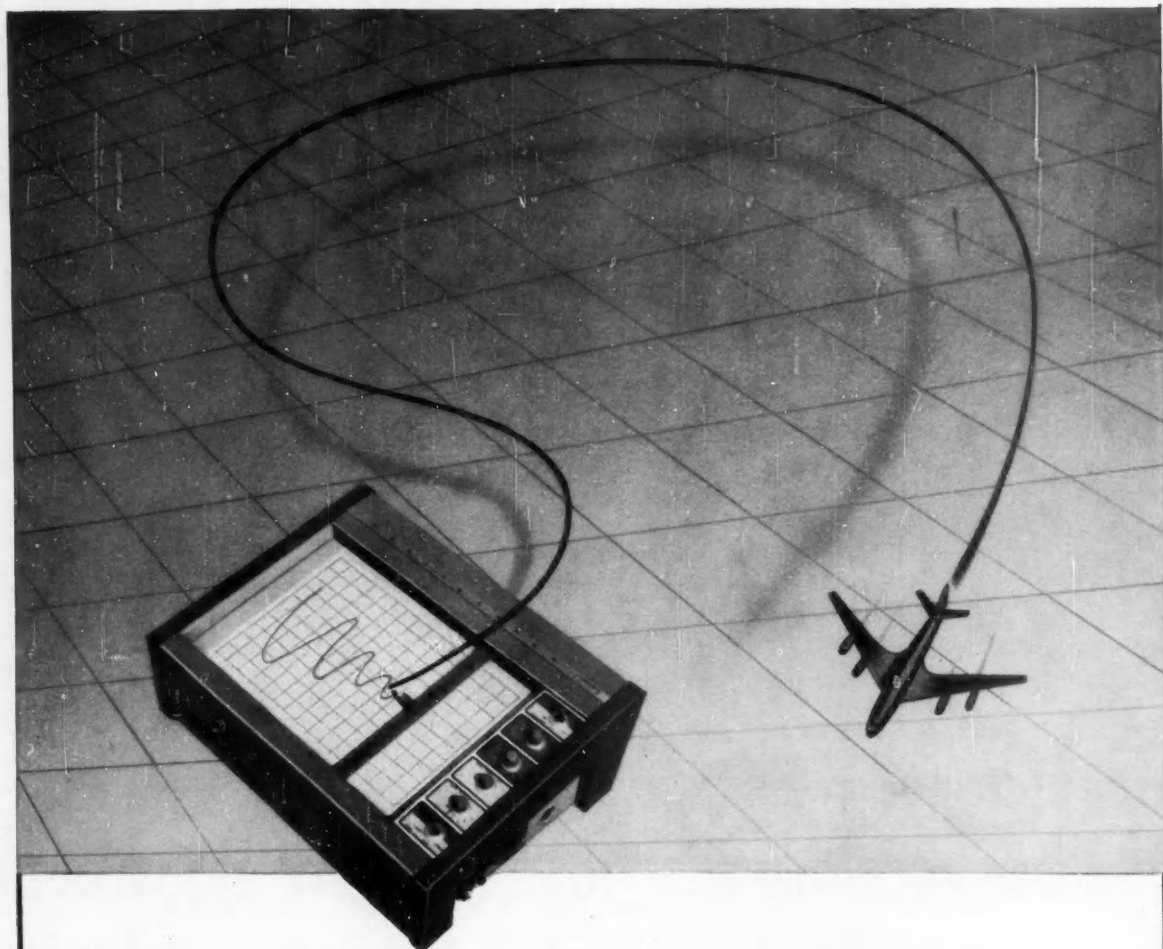
SPECIFICATIONS

Weight95 pounds
Differential Current	± 8 m.a.
Coil Resistance	1500 ohms
Coil Inductance2 henries
Flow Rating20 in. 3 sec.
Null Leakage4 in. 3 sec.
Operating Pressure	500 to 3000 p.s.i.
Operating Temperature	-65 to 450°F.



PEGASUS LABORATORIES, INC.

DESIGNERS AND MANUFACTURERS OF ELECTRO-HYDRAULIC SERVOMECHANISMS
3690 W. ELEVEN MILE ROAD • BERKLEY, MICHIGAN



Announcing a new member in a proud family

Once again, setting the PACE, Electronic Associates announces the newest addition to the royal family of recording equipment — the new Variplotter Model 1100D.

Another example of the PACE of Progress set by Electronic Associates, the new Model 1100D Variplotter offers 9 specific, built-in operational advantages, as well as 5 new integral convenience factors, to assure the ultimate in X-Y, table-top recording.

Complete specifications on these 9 operational advantages and 5 convenience factors will be forwarded to you on request.

For details on this and other Variplotter models, as well as information on Analog Computing Equipment, time rental at our Princeton Computation Center, or a visit with our skilled Sales Engineering staff, write Dept. CE-1, Electronic Associates, Inc., Long Branch, N. J.

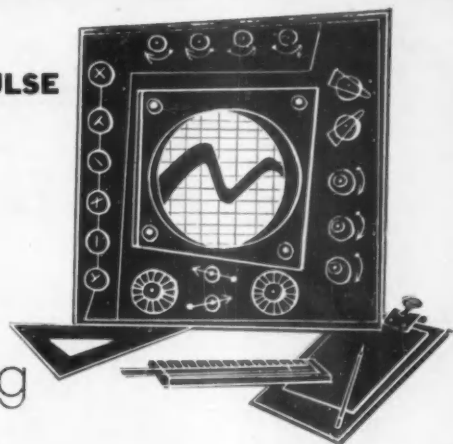
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P A C E
PRECISION ANALOG COMPUTING EQUIPMENT

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The Users Reflect on Automatic Data Logging

November's *Industry's Pulse* reported on how 719 user-readers rate the electronic control techniques that have cascaded into the flow-process control field in the past few years. At its tail-end the report hinted at user-attitudes toward one of the most exciting and controversial of these new techniques: the mechanized gathering of digital process information, or automatic data logging.

Actually, digital data logging is not "new": it dates back almost 20 years to an electromechanical system installed by Commonwealth Edison to read amperage on feeder lines to four Chicago substations. And the techniques evolved in wartime test installations now blanket all of the nation's wind tunnels and engine test cells. Despite its enormous potential, however, data logging has yet to conquer the industrial field: process control users only began adopting these systems two years ago. November's *Pulse* listed just 110 flow-process subscribers with data logging experience out of the 685 who answered the pertinent query—and most of the 110 come from the few companies with the installations.

Since most industrial processes are already well-equipped with recording and indicating instrumentation, justifying a new information-gathering system to management is perhaps the biggest barrier facing the pioneering industrial user. Let's see how 532 respondents to the survey rate nine of the common justifications for data logging:

Justification	No. of Mentions	Percent Mentioning
Info. for process/plant research & analysis	375	70
For labor saving	337	63
To help plant or operation supervisor	322	61
To provide trouble-shooting information	315	59
Info. for accounting or inventory control	307	58
Validity of data	271	51
To simultaneously read several variables	239	45
To help operator on shift	220	41
To experimentally evaluate such systems	146	27

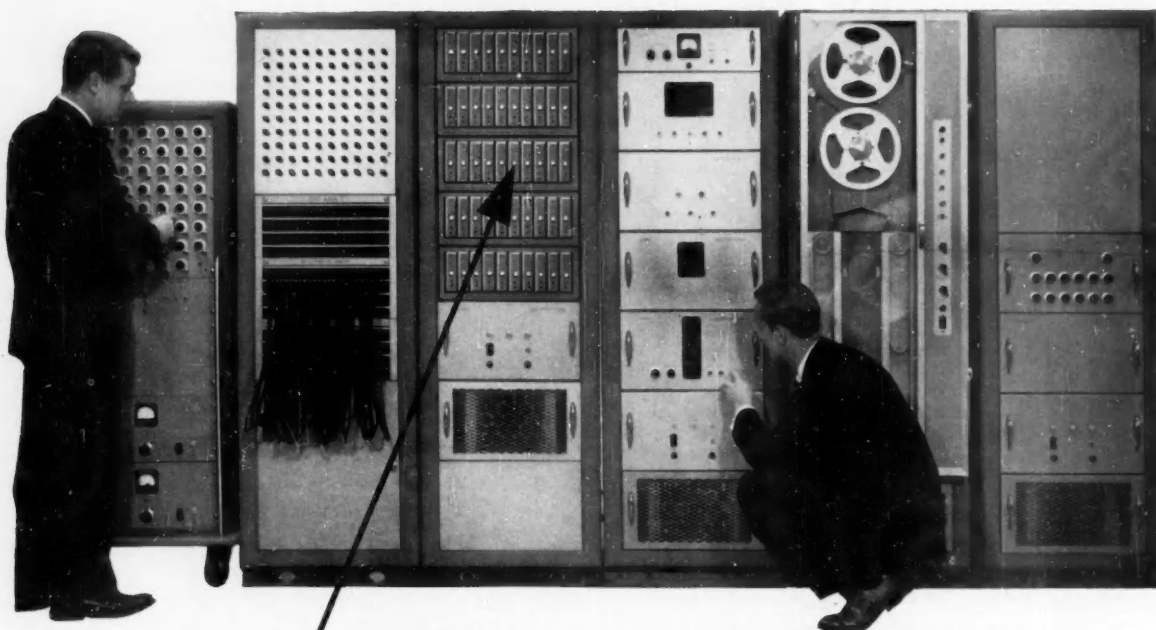
Note: Total exceeds 100% because some respondents mentioned more than one item.

The fact that more than half the group felt obliged to call on six of the nine reasons indicates that an all-important justifi-

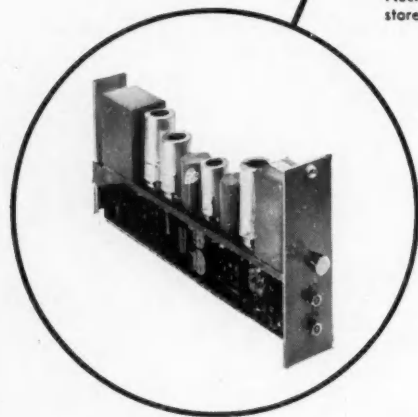
It really got started in '38

The big problem: justification

Doelcam Preamplifiers combine isolated input with accuracy of 1 part in 2,000 in the CEC MilliSADIC




Consolidated Electrodynamics Corporation's MilliSADIC Installation for General Electric's Aircraft Nuclear Propulsion Dept., Cincinnati samples 400 jet engine temperatures per second and stores this information in digital form.



Doelcam Data Handling D-C Amplifier, Model 2HDH-2. This type is used as preamplifiers in the CEC MilliSADIC shown above.

The *isolated input* of the Doelcam Data Handling D-C Amplifiers, Model 2HDH-2 makes them ideally suited as preamplifiers to raise the input signals from thermocouples and strain gauges to the level required by the analog-to-digital conversion system of CEC's MilliSADIC installation at General Electric's Aircraft Nuclear Propulsion Dept., Cincinnati. The low noise level, high degree of linearity and zero and gain stability of these amplifiers provide the accuracy of 1 part in 2,000 required for this application. The exclusive Doelcam Second Harmonic Converter as the input element of these amplifiers provides the bonus features of ultra high common mode rejection and resistance to pick-up.

Doelcam Data Handling D-C Amplifiers, 2HDH Series, are compact plug-in, rack-mounted units specifically designed for use as preamplifiers in data processing systems. These amplifiers are available in the input range, rise time, frequency response or gain specifications required by many data processing systems. Other amplifiers in this series can accept as many as 150 separate D-C signals per second. Write for Bulletin 2HDH . . . Doelcam, Dept. 34, a Division of Minneapolis-Honeywell, 1400 Soldiers Field Road, Boston 35, Mass.

Honeywell 
DOELCAM DIVISION

cation is still lacking for the potential data-logger user. However, the favored answer—aid in process or plant research and analysis—is an intriguing one. It suggests that to many data logging is a tool rather than a machine—a means to an end rather than an end in itself. And what is the “end”? Possibly an ironic one: replacement of the logger by a process plant computer as a direct result of this same research and analysis.

More definite answers were made to queries on specific data logging techniques. Is continuous scanning an important supplementary feature? It is important, said 308; the remaining 74 dissented. Are electric or electronic control instruments desirable with data logging? To this query, 326 replied yes; 64 indicated they are not desirable. Even greater affirmation was prompted by the question, “Is off-normal printout useful?” In this case 360 out of 387 considered this a useful function. Answers concerning printout methods in data logging systems favored the wide carriage typewriter (207 of the 374 who considered this question); 88 were sold on the standard carriage, and the remaining 89 liked teletype as a means for printout. Storage device preferences were much less clean-cut: 175 went for punched cards, 107 took to punched tape, 136 said they’d bank on magnetic storage.

The users were also asked for their views on the relation of data loggers to the more conventional “trend recorder” methods for gathering data. Almost all—463 out of the 532 who answered—believed that the two methods will complement each other for years to come. Only 36 felt that data logging has no chance of eventually supplanting line recorders. And only 45 thought the opposite: that the data logger will, in time, completely obfuscate the familiar round and strip charts of the process plant.

The final question on data logging was aimed at the pocket-book. How long, it asked, are you willing to wait for a data logger to start paying for itself? The answers:

1 year	42	5 years	105
2 years	107	6 years	7
3 years	94	7 years	38
4 years	32	8 years	1

Next—the process plant computer?

Storage methods a toss-up



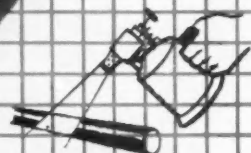
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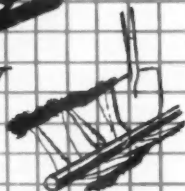
NEW LINEAR POLYETHYLENE



YOU CAN BURN IT



YOU CAN BANG IT



YOU CAN BURY IT

You can't beat all-plastic Dekoron Poly-Cor for chemical resistance or for ease of installation. And now, the new Dekoron Instrument Tubing Harness adds yet another revolutionary feature—fire resistance.

For example, in the direct flame of a cutting torch, it lasted longer than any other multiple-tube harness. Use it in areas where flash fires

are a hazard. And new Dekoron Instrument Tubing Harness is rugged, too. You can bury it and forget it.

You get all the advantages—chemical, impact and fire resistance—with new Dekoron Instrument Tubing Harness. Remember, you can burn it . . . you can bang it . . . you can bury it. And you can buy it now.

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A Unesco for Control?

We think that all control engineers, no matter what their technical society or national allegiance is, will welcome this latest news on the prospects for an international federation in their field (see CtE, December '56, pp. 32-33, for a statement on the Resolution for this federation, which was issued at Heidelberg, Germany, last September). Since Heidelberg, technical society groups in Japan, France, Norway, Switzerland, Yugoslavia, and Poland have pledged support in principle, while British and Belgian groups await action by North America. And we can now report that representatives of ASME, AIEE, IRE, ISA and SAE met on Nov. 29 at the invitation of ASME President J. W. Barker and agreed to recommend to their boards that they appoint delegates to a North American committee. This committee will meet shortly after Feb. 1, to select a delegate to an international organizing body and to deliberate on objectives, a constitution, financing, and operation of the proposed international federation.

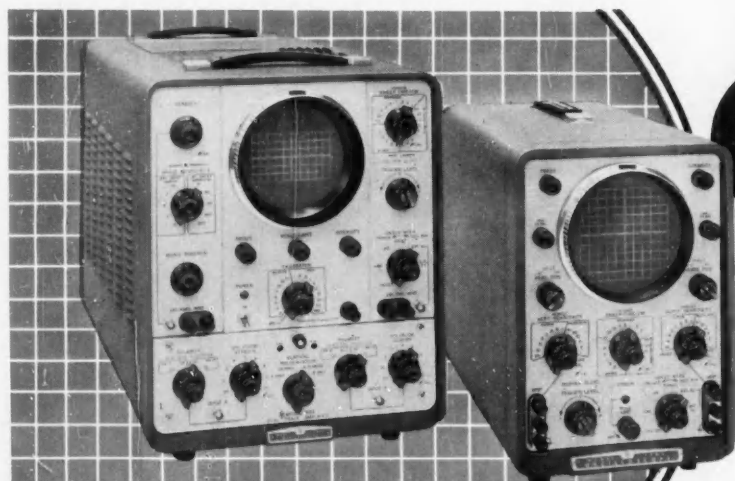
Why an international federation? Its general goals—improving the exchange of information on control systems engineering and promoting progress in the field—would seem to fall squarely within the scope of an already established international agency: The United Nations Educational, Scientific, & Cultural Organization. UNESCO seeks to

- ▶ “stimulate the free flow of ideas and cultural achievements in all parts of the world.
- ▶ “encourage the cooperation of scientists and make available the results of their research.
- ▶ “translate great literary, philosophic, and scientific books.”

The like aims of the control engineering federation suggest that it operate directly under UNESCO. But perhaps many of the engineers working towards union fear that under UNESCO the union could become just one more international political football, punctured with canny timing by vetoes. The organizers appear to prefer their own supervision—limited only by the wishes of their national professional societies and by the regulations of their governments. We are told that our State Department, at the moment, approves and encourages this independent approach.

The start of a new year is an appropriate time to support a hopeful new venture. But as we add our enthusiastic endorsement and backing to the Heidelberg Resolution, we should also hold one “ground rule” as sacred in its development: that it be primarily dedicated to the individual. As in the recent Olympic games, the “gold medals” should continue to go to individual winners and not to national teams.

THE EDITORS



Announces
2
all new

OSCILLOSCOPES

BRIEF SPECIFICATIONS

-hp- 130A

Sweep Range: 1 $\mu\text{sec}/\text{cm}$ to 15 sec/cm .

Calibration: 21 sweeps: 1-2-5-10 sequence, 1 $\mu\text{sec}/\text{cm}$ to 5 sec/cm . 5% accuracy.

Triggering: Internal, line voltage or external 2 v or more. Pos. or neg. slope, +30 to -30 v trigger range.

Preset Trigger: Optimum setting for automatic stable triggering.

Input Amplifiers: (Similar Vert. and Horiz. Amps) Sensitivity 1 mv/cm to 50 v/cm; 14 ranges, continuous vernier. Pass band dc to 300 KC.

Amplitude Calibration: 1 KC square wave. 5% accuracy.

Price: \$450.00.

-hp- 150A

Sweep Range: 0.02 $\mu\text{sec}/\text{cm}$ to 15 sec/cm .

Calibration: 24 sweeps: 1-2-5-10 sequence, 0.1 $\mu\text{sec}/\text{cm}$ to 5 sec/cm . 3% accuracy.

Triggering: Internal, line voltage or external 0.5 v or more. Pos. or neg. slope, +30 to -30 v trigger range.

Preset Trigger: Same as -hp- 130A.

Horizontal Amplifier: Magnification 5, 10, 50, 100 times. Vernier selects any 10 cm part of sweep. Pass band dc to over 500 KC. Sensitivity 200 mv/cm to 25 v/cm.

Vertical Amplifier: Pass band dc to 10 MC. Optimum transient response and rise time less than 0.035 μsec . Signal delay of 0.25 μsec permits leading edge of triggering signal to be viewed.

Amplitude Calibration: 18 calib. voltages, 2-5-10 sequence, 0.2 mv to 100 v peak-to-peak. Accuracy 3%. Approx. 1 KC square wave, rise and decay approx. 1.0 μsec .

Prices: -hp- 150A High Frequency Oscilloscope, \$1,000.00.

-hp- 151A High Gain Amplifier, \$100.00.

-hp- 152A Dual Channel Amplifier, \$200.00.

Data subject to change without notice.

Prices f.o.b. factory.

-hp- 130A Low Frequency Oscilloscope

High sensitivity, dc to 300 KC. Sweeps 1 $\mu\text{sec}/\text{cm}$ to 15 sec/cm .

-hp- 150A High Frequency Oscilloscope

Dc to 10 MC. Plug-in preamplifiers. Sweeps 0.02 $\mu\text{sec}/\text{cm}$ to 15 sec/cm .

As a result of a totally new design philosophy, -hp- 130A and 150A Oscilloscopes set revolutionary standards for oscilloscope usefulness, convenience and rugged dependability. The instruments' wide versatility is indicated in the specifications at left. Their greater convenience and reliability is inherent in such unique features as: Universal automatic triggering system wherein one preset adjustment provides optimum triggering for almost all conditions. Unitized circuits, easily isolated for testing. Etched circuits, mounted on translucent plastic for "see-through" serviceability. Complete accessibility of all circuits and tubes. Highest quality components. Ultra-conservative design, with circuits operating well below ratings. Concentric, color-coded controls, grouped by function and simplified. Direct sweep time selection—no mental gymnastics. A new low capacitance clip-on probe (for -hp- 150A) has 10 megohm impedance.

Get complete data on the most important oscilloscope improvements in history! Call your -hp- representative now, or write direct!

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Field engineers in all principal areas

Now, more than ever, -hp- means "Complete Coverage"

Control Tools Develop A New Navigational System

Dead reckoning or position indicating systems for moving vehicles up to now have been either self-contained or externally referenced. The new self-correcting technique described here combines the best features of each approach and improves overall accuracy by minimizing the shortcomings of the separate methods. The components and circuits involved in the new system are relatively simple, and its conception—based on the principles of statistical processes and information theory—represents an interesting departure from conventional methods.

D. J. GREEN, Learcal Div., Lear, Inc.

The self-correcting automatic navigator, developed by Lear, Inc., consists of self-contained dead-reckoning instrumentation and a ground referenced position-indicating system, interconnected to operate as shown in Figure 1. The data from the two navigational systems are compared and any difference is then applied to an "optimum" filter. The output of the filter supplies correction data that causes the self-contained system (the dead-reckoning computer) to come into long-term agreement with the data supplied by the external (ground referenced) system. For simplicity, the "self-contained" system discussed here will be of the true-airspeed (TAS) and heading (supplied by either compass or directional gyro reference) type and the externally referenced system (employing polar coordinates) will be called the "radio system". The basic technique applies to any combination of practical methods, not only to the methods used for illustration. The only restriction imposed is that the information from one of the data sources must be transposed into the coordinates of the other so that both use the same units and coordinates.

Weaknesses of existing systems

Dead-reckoning or inertial methods measure velocity or acceleration and integrate the measured quantity to determine distance traveled. The main weakness of this and most other practical self-contained systems is the loss of accuracy with time. Radio systems suffer from line-of-sight limitation and are susceptible to jamming. However, the weakness of both methods can be eliminated by properly supplementing one by the other, allowing the dead reckoner to accept correction data from the

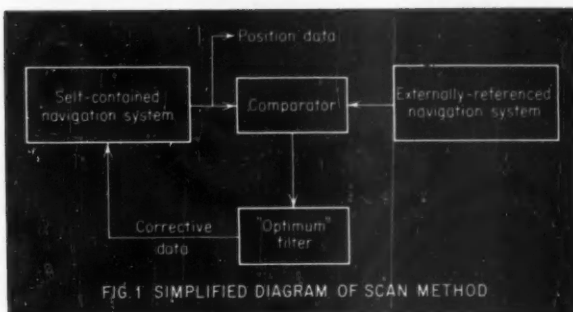
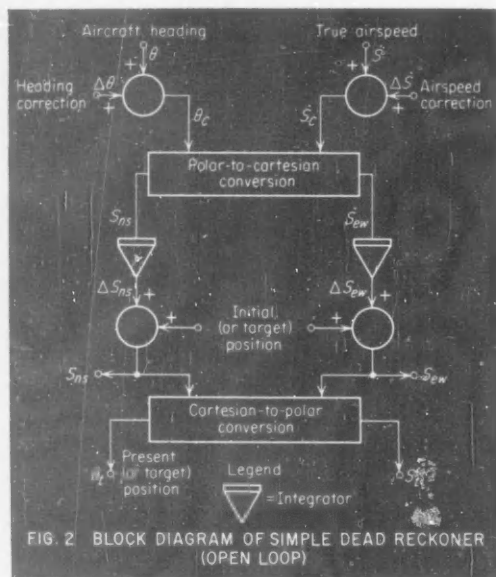


FIG. 1 SIMPLIFIED DIAGRAM OF SCAN METHOD

radio system. Since the airborne instrumentation can be designed for good long-time memory, it can act as a smoothing filter for the radio data. It remains essential, however, that the system examine all samples of radio data for valid data, often hidden in false, or noisy, data. The technique for examining data prior to acceptance is based upon the predictable accuracy of the airborne system. Flights usually originate in areas that provide essentially continuous radio data and, in the system described, this continuous data will calibrate, or correct, the measurements used for dead reckoning.

Simple open-loop system

A very simple dead reckoning system is block-diagrammed in Figure 2. The input data is heading, θ , and true airspeed, \dot{S} , and such corrections, $\Delta\theta$ and $\Delta\dot{S}$, as are known. The corrected data, θ_c and \dot{S}_c , are then transformed from their polar coordinate form into \dot{S}_{ns} and \dot{S}_{ew} , the aircraft velocity components along arbitrarily chosen north-south and east-west ordinates. Integration of these components calcu-



lates the distance traveled as expressed in the Cartesian form, ΔS_{ns} and ΔS_{ew} . The addition of initial position at the outset of the flight gives present Cartesian position S_{ns} and S_{ew} ; conversion to polar form gives data on bearing, θ_t , and distance S_t , from the coordinate center.

Validity of radio data

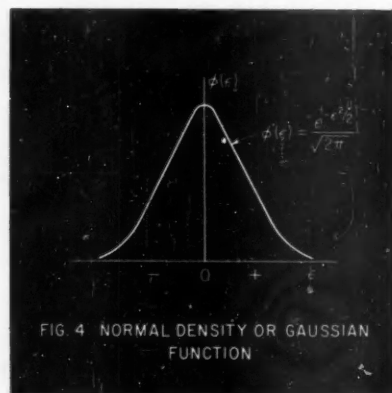
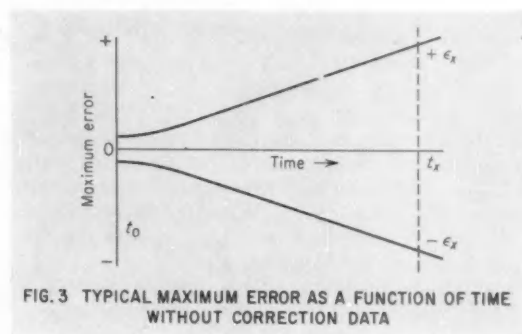
In a system of the general class just described, where the sources of error are known, maximum drift rates can be established. If correction data ($\Delta\theta$ and $\Delta\dot{S}$) have been supplied to the equipment over a period of time, the dead reckoning will read correctly within the limits of the correction data. Figure 3 shows that if further corrections are denied the equipment at time t_0 , the maximum error will increase at a known rate as time progresses.

To determine the probable validity of any sample of radio data it is only necessary to know the state of the dead-reckoning system. If radio data have been continuously correcting the system, the acceptance range of data can be made relatively small, as indicated by the small possible positional error shown at t_0 in Figure 3. However, if there has been an interruption of time t_x , the possible dead-reckoning error might be as large as plus or minus ϵ_x and the acceptance range must be increased. Since the present indicated position plus or minus ϵ_x represents the confidence limits of the airborne data, all errors in excess of this amount can be disregarded. Nevertheless consideration must be given to the weighting or credibility coefficient for data within the limits.

Statistical processes at work

Since the short-term errors generated within the

self-contained system are largely random (e.g., uncompensated gyro drift and noise), statistical processes can be applied effectively. Error values between the confidence limits will likely follow the normal density function of Gaussian law illustrated in Figure 4, where $\phi(\epsilon)$, the relative probability of an error of value ϵ , is normalized to a maximum value of unity. (The normal density function approaches zero as ϵ approaches plus or minus ∞ . In this practical application it is arbitrarily given a value of zero when the function attains a value at the resolution threshold of the instrumentation.) Physically, the weighting or credibility coefficient is maximum for radio data indicating zero or small errors and very low for large errors near the confidence limits. The low weighting of large errors reflects their improbability and requires the radio data to repeat this information a greater number of times before the correction is learned. Smaller errors are learned more quickly. In all cases the integrator constants are very long compared to the data intervals and information must be sustained to be assimilated. Use of two data sources will improve accuracy only if one set of data



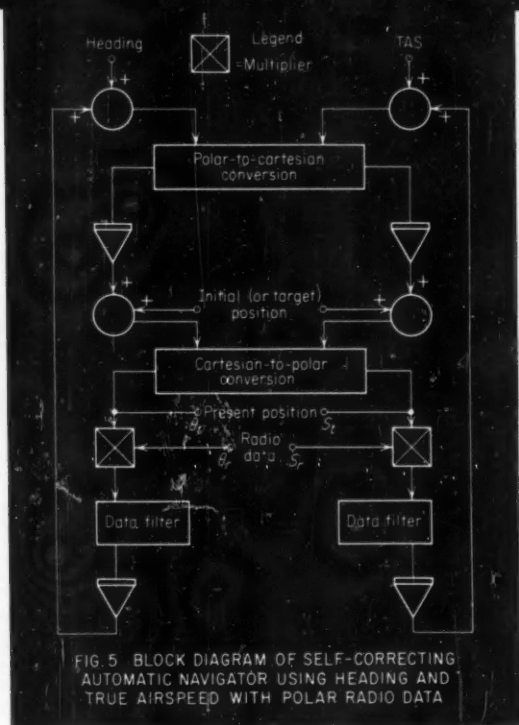


FIG. 5 BLOCK DIAGRAM OF SELF-CORRECTING AUTOMATIC NAVIGATOR USING HEADING AND TRUE AIRSPEED WITH POLAR RADIO DATA

is filtered with respect to the other, or if effectively-infinite integration intervals are permitted.

Operation of new system

The block diagram in Figure 2 is extended in Figure 5 beyond the points where the locally measured heading and TAS are entered at the terminals—i.e., where present position, θ_t and S_t , are available.

At these points the radio-derived position data, θ_r and S_r , are subtracted from the dead-reckoned position, and the indicated error in angle and range is processed in a data filter to establish its credibility coefficient. This operation will be described later. The weighted error in each channel will be integrated to determine the correction applied at the corresponding dead-reckoner input. A rate network preceding the integrator may be required to provide stability in each of the overall loops, since each loop contains two cascaded integrators. Double integrator loops for dead reckoning result in compound filtering of noise or random inputs and provide memory for computing through intervals in which radio reception is interrupted.

Figure 6 shows a simplified double integrator loop. If range is the dimension being tracked, the input range from the radio system, S_r , is compared with the current value of the tracking loop output to determine errors. Errors are integrated until the output agrees with the input. Such agreement can be virtually perfect when S_r is either static or changing at a constant rate. Since the value S is the output of an integrator, the inputs to the first and second integrators must be the first and second time-derivatives of range.

In Figure 7 the loop is modified to provide for the

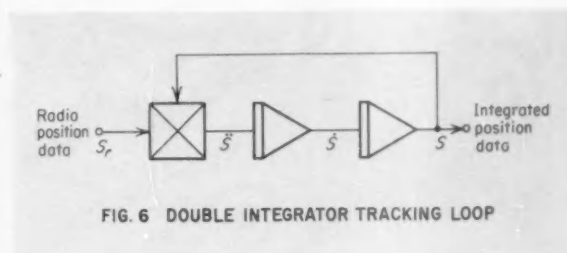


FIG. 6 DOUBLE INTEGRATOR TRACKING LOOP

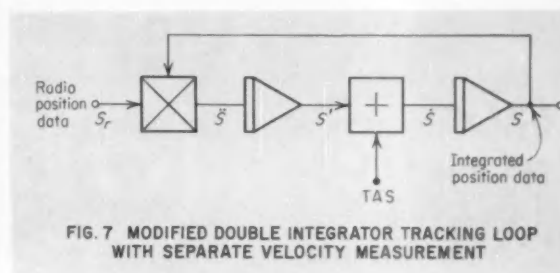


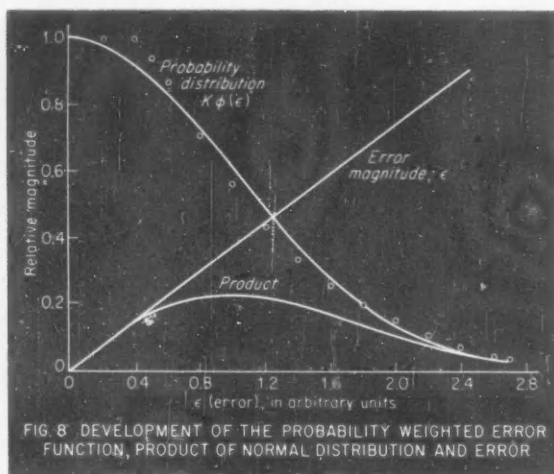
FIG. 7 MODIFIED DOUBLE INTEGRATOR TRACKING LOOP WITH SEPARATE VELOCITY MEASUREMENT

separate measurement of velocity (TAS). If the TAS were equal to the value of \dot{S} necessary to permit accurate position prediction, the value of \ddot{S} and S' would be zero. However, since the radio data will vary with ground speed, S' will assume a value which is the difference between TAS and ground speed, or equal to the wind magnitude. In an identical manner, the correction in the heading channel will account for differences between indicated heading and ground track.

Data filtering

The process for weighting the error signal by the normal density function involves multiplying. Figure 8 shows one-half of the density function, a constant slope line signifying error magnitude, and the product of these two functions. The product, the weighted error function, represents the output of the weighting device for various magnitudes of error input. A measure of the simplicity of the entire data filtering and probability-weighting section can be gained from

DEFINITIONS	SUBSCRIPTS
θ = angular heading	c = corrected data
S = position (or range)	ns = north-south
\dot{S} = true airspeed	ew = east-west
S' = ground speed	t = data at present time
\ddot{S} = acceleration	r = radio derived data
e = error magnitude	
t = time	



the fact that three vacuum tubes (or their transistor equivalents) and other standard commercial components will perform the entire operation.

Selecting components

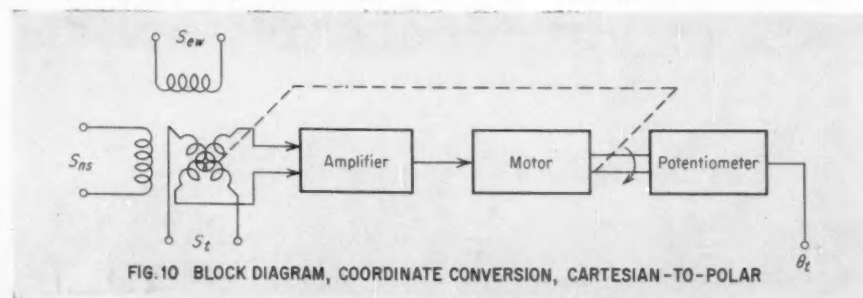
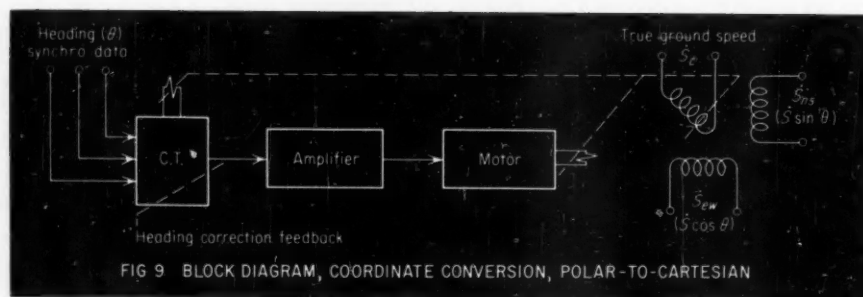
The system components can be largely electro-mechanical. The four integrators should be mechanical to assure long-time memory and freedom from transient effects such as power-supply interruption. This calls for a rate tachometer feedback from the motor output for comparison with the input in assuring proportionality of integration. The motor, through gear reduction, drives a precision potentiometer to accumulate the integral.

Coordinate converters can be electromechanical

servos. Figure 9 illustrates a technique for converting polar data into Cartesian form. Heading data, generally available from synchros attached to directional gyros or flux gate compasses, are applied to a control transformer (CT) to direct an angle repeating servo which also rotates a resolver. The resolver rotor is thus turned to the heading angle, θ . If the rotor is excited with a carrier voltage proportional to ground speed, the two stators then deliver the resolved north-south (\dot{S}_{ns}) and east-west (\dot{S}_{ew}) velocities. The correction to the aircraft heading to cause it to represent ground-track bearing, as derived from filtered and integrated radio data, is shown introduced by mechanical rotation of the CT case through the corresponding angle. The airspeed correction will have been added to the TAS value prior to application to the resolver.

Conversion from Cartesian to polar coordinates is diagrammed in Figure 10. The signals denoting present aircraft position are applied to the stators of a dual-wound rotor resolver, whose two rotor windings are precisely normal to each other. One of the rotor windings is used as the input to a position servo which continuously drives that winding into the resolver field null. The other winding reads the total vector, or polar distance S_t . The servo shaft position, which can be reported electrically from a 360-deg potentiometer, represents bearing from the coordinate origin, θ_t .

Addition and subtraction can be accomplished electrically or mechanically using such standard methods as resistive addition, in-phase or out-of-phase voltages, and differential gear mechanisms.



Modifying Valve Characteristics to Fit the Process

GILBERT L. ROTH, Convair, Fort Worth

A little over a year ago in these pages Gil Roth covered the important factors in selecting a valve ("Factors in Selecting Valves for Compressible Flow", *CfE*, December '55, pp. 46-53). He showed that the variety of valve types and system resistances to flow provided numerous mass flow characteristics. In this issue he discusses a mechanism between the actuator and the valve that modifies these characteristics to more nearly meet good flow control requirements in the process.

A linkage of three or four bars is the intervening mechanism. Typical ranges of modification possible with it are portrayed graphically for slide, poppet, and butterfly valves. An example illustrates a graphical technique for finding the specific linkage design necessary to meet a desired flow characteristic with a standard valve. Torque amplification curves for these linkages aid in determining the torque needed at the driver.

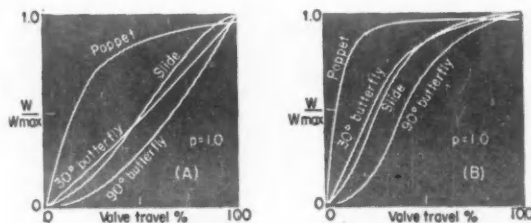


FIG. 1. The mass flow characteristic varies not only with valve type, but also with the flow resistance of the system in which the valve controls the flow.

Control valves, in many applications, throttle the mass flow of material smoothly and continuously with changes in valve stem position. The nature of the resulting flow performance depends on several factors:

- ▶ valve type, such as slide, poppet, or butterfly
- ▶ system resistance
- ▶ valve's inherent resistance.

Figure 1 shows the variety of flow stem-travel characteristics obtainable from these valves at two conditions of system resistance, as derived from:

$$\left(\frac{W}{W_{\max}}\right)^2 = \frac{1}{1 + p \left[\left(\frac{A_{\max}}{A}\right)^2 - 1 \right]}$$

The equation gives the flow characteristic in terms of the valve's open area A , but this area varies uniquely with stem travel for each type of valve.

Frequently the overall design requirements force the choice of a certain valve type, and the flow characteristic that results may be unsuitable for good control of the process. This natural characteristic can be modified to suit process requirements simply by introducing a nonlinear mechanism between the valve stem and the valve actuator.

Many mechanical devices can be used in this way; however, the present discussion will be limited to:

- ▶ the three-bar sliding center link, with rotational input and translational output, for poppet and slide valves
- ▶ the four-bar fixed-center link, with rotational input and rotational output, for butterfly valves

Three-bar linkages

Figure 2A shows the schematic arrangement of an on-center three-bar linkage driving the valve stem of a slide or poppet valve. The total rotational input motion here is 180 deg. The resulting translational motion X is given by the expression:

$$X = L(n + 1 - n \cos \alpha - \cos \theta), \text{ where } \sin \alpha = \frac{\sin \theta}{n}$$

The curves in this figure show the graphical solution of the equation for various values of n . Variations in link length shift the curve any way desired.

Additional motions can be obtained from the three-bar linkage by placing the point about which

VALVE AND LINKAGE SYMBOLOLOGY

p ,	a dimensionless factor indicating relationship between valve resistance and overall system resistance:
$p = \frac{\text{Pressure drop across wide open valve}}{\text{Pressure drop across valve + system}}$	
W ,	fluid mass flow, lb/sec
W_{\max} ,	fluid mass flow, wide open valve, lb/sec
θ ,	actuator or driven link angular motion, deg
nL ,	linkage length, where n varies from 2 to 10, usually
X ,	poppet valve stem movement, in. (linear valve movement in general)
D ,	poppet valve seat diameter, in.
Y ,	distance center of rotation of driving link is removed from centerline of valve stem, in.
α ,	angle between connecting rod and valve stem; see Figure 3A
A_{\max} ,	maximum open valve area, in ² .
A ,	open valve area at any stem position, in ² .

the actuator rotates above or below the valve stem sliding center line. Figure 2B shows the resulting characteristics at $n=2$. Here off-center actuation permits a choice of quick-opening or slow-opening valve characteristics.

Four-bar linkages

The equations that describe the displacement, velocity, and acceleration of points on a four-bar linkage are long and unwieldy, making mathematical synthesis very tedious. However, a graphical analysis is possible using the curves of Figure 3. These curves indicate that changes in the fixed link length (actuator center of rotation to valve-stem center of rotation) have little effect on the actuator-to-valve-stem travel ratio.

Valve and linkage characteristics

Figure 4 shows flow characteristics for a poppet valve with a three-bar linkage between the valve stem

and the actuator. Here, n equals 2. In one case the actuator is on-center, in the other it is off-center.

Figure 5 shows the flow characteristics for a slide valve using the same linkage and actuator arrangements for Figure 4. Again the valve can be modified over a wide range of values.

Figure 6 shows the wide variety of flow characteristics that can be obtained from 30- and 90-deg butterfly valves with the four-bar linkage and several different R to L ratios. At 0.1p, adding the four-bar linkage to the 30-deg butterfly valve yields a flow-actuator characteristic that is fairly linear compared with the highly nonlinear characteristic for the 30-deg butterfly valve alone. This drastic change in the overall flow characteristics illustrates the variations and improvements that can be obtained by adding an appropriate linkage between the actuator and the valve stem.

Selecting correct linkage

Typical modifications, or characterizations, in flow vs. actuator travel that can be obtained with three- and four-bar linkages have been indicated in the preceding figures. Now the problem of selecting an appropriate linkage to obtain a desired flow vs. actuator travel characteristic must be tackled. The following example shows one graphical approach to obtaining this answer.

The application requires the use of a poppet valve. The system's resistance to flow is negligible so that p equals 1.0. To obtain a transitory motion for the valve's stem travel requires a three-bar linkage between the rotary driver and the valve. The desired flow characteristic equals the product of the inherent valve characteristic and the linkage characteristic. The desired flow characteristic (X) is shown in Figure 7 and the inherent valve characteristic (Y) is

FIG. 2. Three-bar linkage gives a significant variation of valve stem-actuator characteristics.

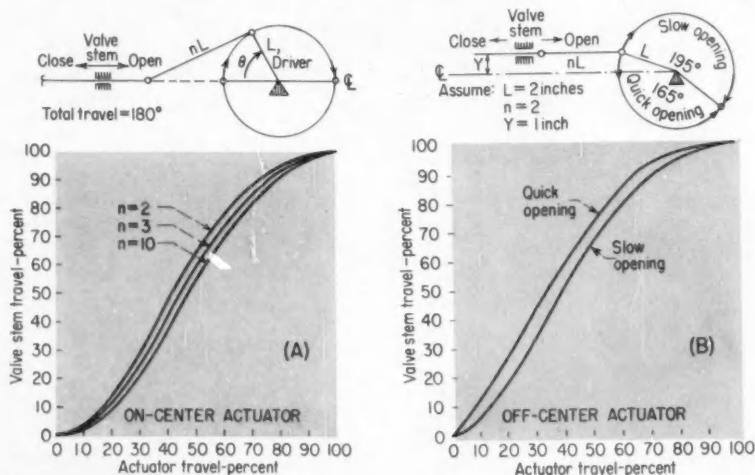
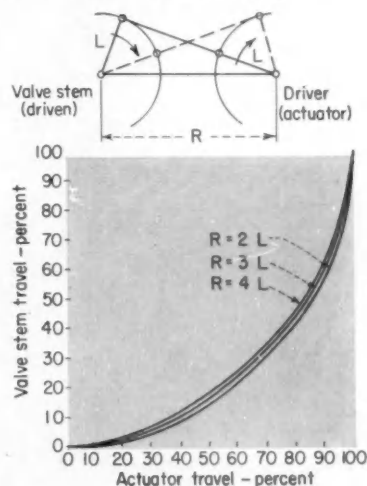


FIG. 3. Four-bar linkage design varies characteristic slightly.



FLOW CHARACTERISTICS:

FIG. 4. Poppet valve with three-bar linkage

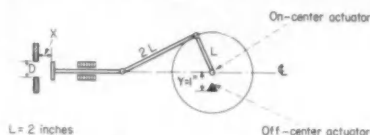


FIG. 5. Flat slide valve with three-bar linkage

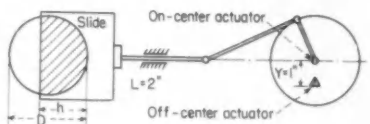
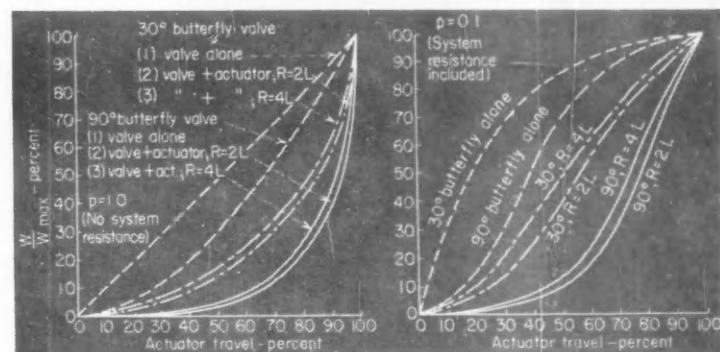
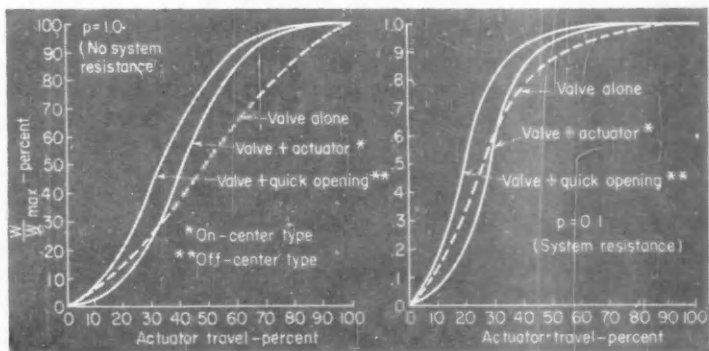
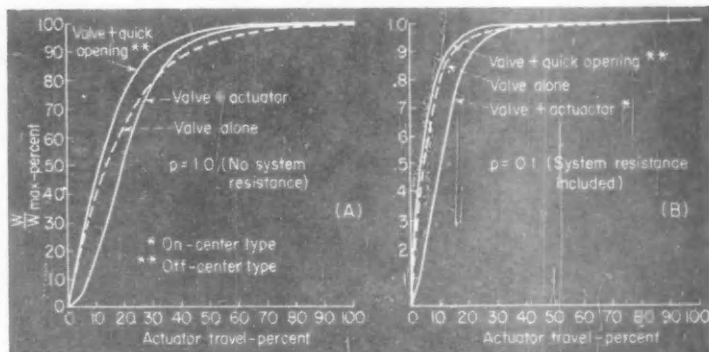
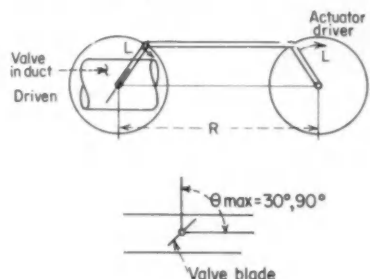


FIG. 6. Butterfly valves with four-bar linkage



shown in Figure 8 for the specific application. Thus, the linkage design Z that will meet the system specifications requires:

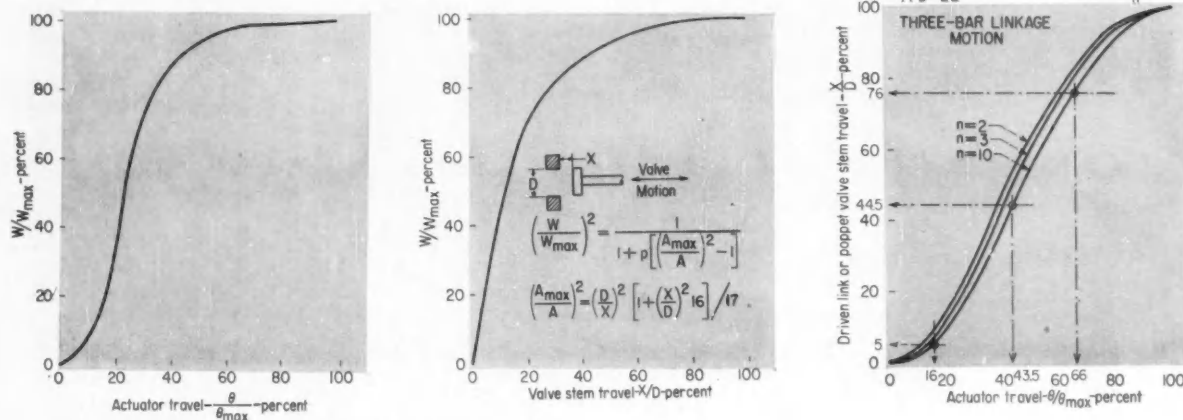
- ▶ dividing X and Y at various flow values
- ▶ comparing the resulting curve with the family of curves of valve-stem travel vs. actuator travel for the three-bar linkage (Figure 2A) to determine the linkage ratio n which most closely fits the desired linkage characteristic.

The procedure for dividing X by Y at various flow values can be simplified by:

- ▶ listing values; thus:

$\frac{W}{W_{max}}$	Curve X actuator travel $\frac{\theta}{\theta_{max}}$	Curve Y valve travel $\frac{X}{D}$
0	0	0
20	16	5
40	21	10.5
60	25.5	17
80	34.5	30
90	43.5	44.5
98	65	76
100	100	100

- ▶ locating corresponding X and Y values from this list on the family of curves for the three-bar linkage.



FIGS. 7, 8, 9. Desired flow characteristic X . . . from standard characteristic Y . . . and three-bar linkage motion Z, where n equals 10.

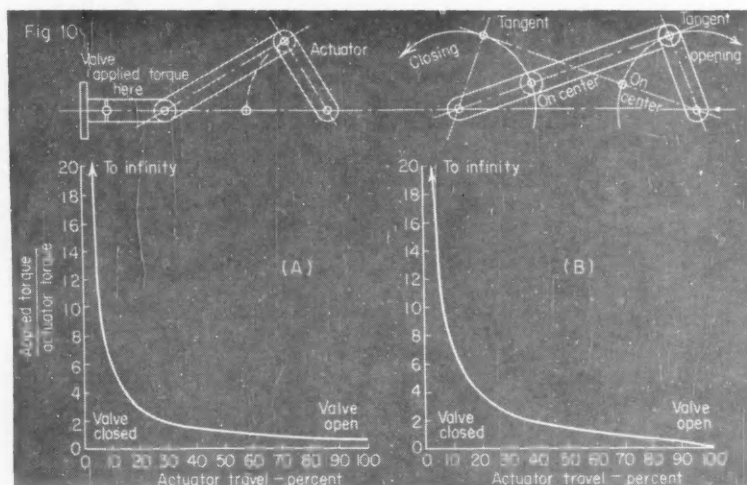


FIG. 10
Linkages amplify
applied torque
at valve stem

Figure 9 repeats Figure 2A, with several points from the list superimposed. These points most nearly match the linkage characteristic for n equals 10.

Therefore, in this application a three-bar linkage with n equal to 10 is needed to obtain the desired flow characteristic (Figure 7) with a poppet valve at p equal 1.0 (Figure 8).

Torques required

The torque experienced by the driving link in three- and four-bar linkages must be known to find the required size and power of the electric, hydraulic, or pneumatic driver. In Figure 10A the torque ratio (applied torque to actuator torque) was obtained for a linkage with actuator link and connecting rod of identical length, and with the actuator travel between the horizontal plane and the angle (approximately 65 deg) at which the links form a right angle. The equation for such a three-bar linkage is:

$$\frac{\text{applied torque}}{\text{actuator torque}} = \frac{1}{2 \tan \theta}$$

The equation of torque for the four-bar linkage is analytically too complex; for this reason the curve of Figure 10B was obtained empirically.

For both linkage types maximum torque is available at the closed position of the valve, where it is required by the combination of maximum pressure loading and the closing and sealing operation. However, the available large torque also permits binding.

REFERENCES

1. FACTORS IN SELECTING VALVES FOR COMPRESSIBLE FLOW, Gilbert L. Roth, "Control Engineering", December 1955, pp. 46-53.
2. MATHEMATICAL SOLUTION OF FOUR-BAR LINKAGES, Guy J. Talbourdet, "Machine Design", May, June, July 1941.
3. SYNTHESIS OF FOUR-BAR LINKAGES FOR THE REPRODUCTION OF DESIRED MOTION PATHS, George L. Nelson, MIT, June 1949.
4. ANALYSIS OF THE FOUR-BAR LINKAGE, John A. Hrones and George L. Nelson, The Technology Press, John Wiley & Sons, Inc., New York, and MIT, 1951.

A THERMISTOR SELECTING SHORTCUT

Metallurgical Products Dept., General Electric Co.

When compensating for resistance changes in measurement and control circuits containing copper, what Thermistor resistance should one use? What shunt resistance across the Thermistor? What will be the maximum deviation over the specified temperature range? Use of this table answers these questions.

Steps:

1. Locate the square at the intersection of upper

(abscissa) and lower (ordinate) temperature limits.

2. Multiply the resistance of the compensated copper by the numbers in the square. Thus:

R_t , resistance of grade 2 Thermistor, = R_c , resistance of compensated copper, times r_t .

R_s , shunt resistance (manganin, cupron, or other low-temperature-coefficient material), = R_c times r_s .

R_{ave} , average network resistance, = R_c times r_{ave} .

3. Read percent deviation directly.

TABLE OF NETWORK COMPONENT MULTIPLIERS FOR TEMPERATURE COMPENSATION

LOWER TEMPERATURE LIMIT, DEG C								
	r_t	r_s	r_{ave}	% Dev.	r_t	r_s	r_{ave}	% Dev.
-60	1.64	0.70	0.38	0.34	0.21	0.20	0.09	
	0.82	0.70	0.63	0.57	0.52	0.50	0.43	
	1.52	1.37	1.28	1.25	1.18	1.17	1.07	
	5.45	5.12	4.42	3.55	3.05	2.13	1.81	
-40	3.26	1.33	0.91	0.53	0.30	0.28	0.17	
	0.82	0.66	0.61	0.53	0.50	0.46	0.41	
	1.60	1.43	1.36	1.28	1.21	1.19	1.12	
	3.82	2.80	2.44	1.83	1.65	1.17	0.73	
-20	2.80	1.82	1.11	0.79	0.49	0.46	0.24	
	0.70	0.61	0.56	0.53	0.49	0.46	0.40	
	1.53	1.43	1.36	1.32	1.25	1.23	1.15	
	3.22	1.69	1.44	1.2	0.97	0.55	0.35	
0	4.13	2.43	1.65	1.01	0.72	0.43	0.25	
	0.69	0.61	0.55	0.51	0.48	0.43	0.41	
	1.57	1.47	1.40	1.33	1.29	1.22	1.16	
	1.76	1.24	0.86	0.76	0.63	0.36	0.31	
+20	4.11	3.55	2.15	1.56	0.95	0.64	0.26	
	0.69	0.59	0.54	0.52	0.48	0.43	0.43	
	1.56	1.51	1.43	1.38	1.31	1.26	1.17	
	1.75	0.78	0.57	0.49	0.37	0.17	0.11	
	+150	+120	+100	+85	+70	+50	+35	
	UPPER TEMPERATURE LIMIT, DEG C							

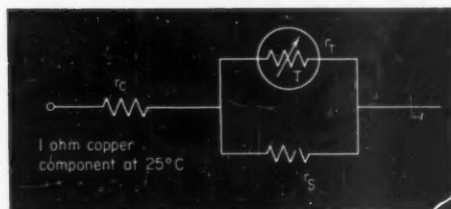
r_t = per unit thermistor, grade 2, resistance at 25°C, ohms.

r_s = per unit shunt resistance at 25°C, ohms.

r_{ave} = per unit average circuit resistance over temperature range, ohms.

EXAMPLE PROBLEM:

Compensate, with a shunted grade 2 Thermistor, a 900-ohm (at 25 deg C) copper coil over a temperature range of minus 60 to plus 85 deg C. Using the intersection of the temperature limits, $R_t = 900 \times 0.34 = 306$ ohms; $R_s = 900 \times 0.57 = 513$ ohms; $R_{ave} = 900 \times 1.25 = 1125$ ohms; % dev. from $R_{ave} = 3.55$.



For a more complete treatment of Thermistor selection, refer to:

1. WHAT'S AVAILABLE FOR COMPENSATING INSTRUMENTS FOR TEMPERATURE CHANGES, Robert Gitlin, CtE, May, 1955.

2. DESIGNING THERMISTOR TEMPERATURE-COMPENSATING NETWORKS GRAPHICALLY, Frank Bennett, CtE, Nov 1955.

The Power Stepping Motor —A New Digital Actuator

A. G. THOMAS and FRED J. FLEISCHAUER The Teller Co.

THE GIST: The increased interest in digital control systems has fostered considerable effort in integrating digital computers into control systems¹, and in developing more fundamental digital transducers². But what about the output power device? Generally these have remained analog, with the output command from the computer or the digital error converted to an analog signal. If digital actuation is desired, however, a new stepping motor (the Digitork), capable of delivering considerable amounts of power, can provide it. This unit is in effect a power computer, since its rate of rotation and angular displacement are accurately determined by the frequency of the current pulses and by the number of these pulses. An open-loop device, it can drive large loads at precisely the correct speed, and position to an accurate angular displacement. No feedback path is required, and the control signal can be obtained directly from a computer, from a storage medium, or from a commutator device.

Stepping motors have been available in the past, but none have been designed for actuator-type service and many have suffered from poor reliability and hunting during stopping. The simple rugged construction of this new unit leads to high reliability, speeds to 100,000 steps per minute, and torque outputs to 3,000 in.-lb. Oscillation about the stopping point is prevented by a reversible overrunning clutch.

The authors give the performance characteristics of several experimental models as obtained from actual tests. Improved performance is expected from standard units soon to be available. Since this stepping motor was originally developed to drive the feed screws on a three-dimensional, film-programmed, contour milling machine, this application is selected to show how to size the motor, and how to provide the proper signal inputs. Other applications, some of which are suggested below, are limited only by the imagination of the reader.

The operation of this type stepping motor is easy to understand. The stator is divided into three spaced sections, or phases, with the same number of poles in each phase and the poles in the three phases aligned axially, Figure 1A. The inner circumferential width of the poles is equal to the inner circumferential spacing between the poles. The poles are wound so that every adjacent pole is of opposite polarity, thereby providing a series of local short-path magnetic fields. Motors have been built with 54, 108, 216, and 360 poles or steps per revolution, and can be made with fewer or more poles if desired. The number of poles per revolution is the total number in all three phases; thus, a 108-pole motor had 36 poles per phase.

Figure 1B shows the rotor that goes with the stator of Figure 1A. The teeth or poles of each rotor unit match the associated stator teeth in number and spacing, but the teeth of each phase overlap the teeth of the preceding rotor unit by $\frac{1}{3}$ -tooth width, as shown in Figure 1C. Therefore, when the rotor teeth of any phase are magnetically snapped into register with the associated stator teeth, the rotor teeth of the next phase to be energized project over the stator teeth of that phase by $\frac{1}{3}$ -tooth width in a circumferential direction. When the second phase is energized, the rotor teeth are brought into alignment with the associated stator teeth, and the rotor teeth of the third phase project over their associated stator teeth by $\frac{1}{3}$ -tooth width. Pulsing the three phases in this order will cause the motor to rotate in discrete steps at a rate depending on the frequency of the pulses. Motor reversal can be obtained by energizing the first and third phases in the opposite order. It is possible to get the same action by aligning the rotor teeth axially, and phasing the stator teeth.

For maximum torque, the rotor poles could also be wound. Torque would be increased by the increased flux density as well as from the electrodynamic effect of the field of the rotor current reacting with the stator field. Ordinarily, however, it is not necessary to wind the rotor, and for many applications it is desirable not to do so, since the windings increase the inertia of the rotor system and necessitate using slip rings.

The action described above actually occurs only

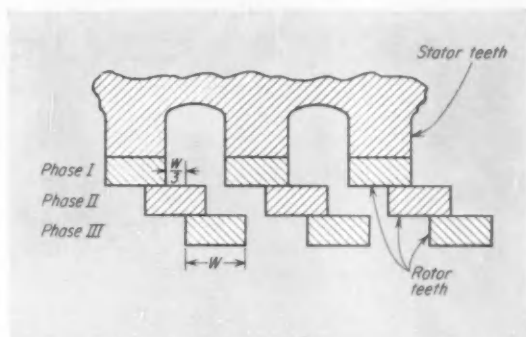
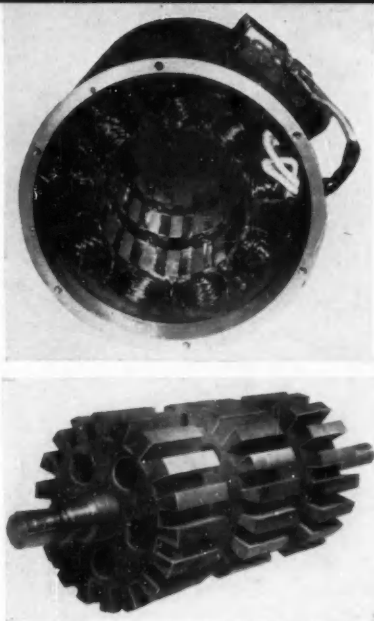


FIG. 1. Stepping motor construction. Stator teeth are in line from phase to phase as shown at left top. Rotor B (left bottom) has teeth shifted $\frac{1}{3}$ -tooth width from phase to phase. This is clearly shown in schematic above.

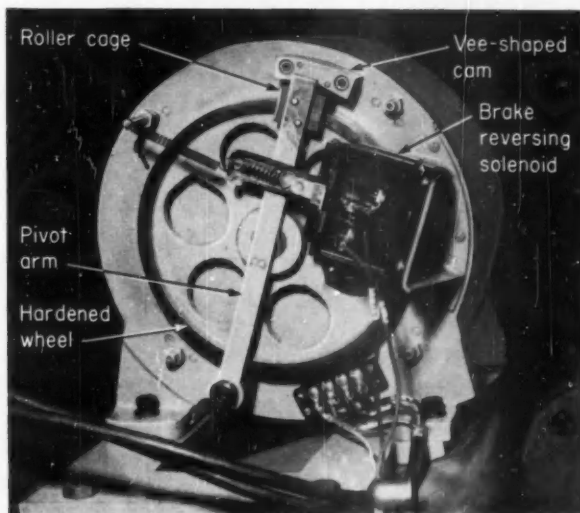
during very slow operation. When the field poles of any phase are simultaneously energized by passing current through their field windings, the out-of-register associated rotor poles will be magnetically attracted, but, due to the momentum of the rotor assembly, will swing past the center or in-register position until stopped by the back magnetic pull. This pull will cause the rotor to swing back past the in-register position in the opposite direction, and the oscillation will continue until the rotor finally comes to rest with the rotor poles in register with the associated stator poles of the energized phase. If the phase energization timing is not accurately matched to the relative positions of the rotor and stator teeth, the force may be applied to the rotor while it is moving forward, accelerating it out of control, or may be applied while the rotor is swinging back, canceling the rotor torque that will bring it to rest. Operation under these conditions is unsatisfactory and impractical.

There are several ways to overcome this difficulty. One is to use electrical or electromechanical timing means to make sure that the phases will be energized only when the rotors are in the optimum (or at least in an operative) position in relation to the stator units. While moderately successful, this arrangement is very complicated; a much simpler method involves the reversible overrunning clutch and this is the one that is used here. Figure 2 shows this device on a 108-pole motor. The brake (or clutch, depending on how it is looked at) consists of a hardened and ground wheel attached to the motor shaft, and an auxiliary roller and inverted V-shaped cam. If the diameter of the roller, the angle of the cam surfaces with respect to the wheel, and the distance between the cam and wheel are properly chosen, the wheel and motor rotor will be locked in one direction, and will rotate freely in the other. The cage holding the auxiliary roller is attached to a pivot arm, so that the roller is pulled against one surface of the V-shaped cam by a spring, and against

the other surface by energy applied to the solenoid. Thus, the direction of free rotor rotation can be reversed by energizing or deenergizing the solenoid.

This simple device is effective in preventing the oscillations and uncertain operation described previously. It is interesting to note that the locking action occurs at zero speed and without shock, just as the rotor starts to swing back to the aligned position with respect to the stator. Operation is hunt-free, and the motor can respond to any practicable rate of phase energization for either direction of rotation. The experimental motors have been run through millions of steps with no detectable wear of the brake surfaces. The rotor poles are not truly aligned with the corresponding stator poles when the rotor assembly locks against backswing, but this makes little difference, since the motor is usually geared to the driven member in such a manner that the required accuracy is achieved with a tolerance of one full step of rotor movement.

FIG. 2. One-way brake on 108-pole motor.



Performance characteristics

PHYSICAL CHARACTERISTICS OF STEPPING MOTORS

Motor	Number of poles	Outside diam, in.	Length, in.	Rotor diam, in.	Axial length of each rotor unit, in.	Air gap, in.
A	108	11	6	7	$\frac{1}{2}$	0.005
B	360	6	$5\frac{1}{2}$	3	$\frac{1}{2}$	0.004
C	108	10	7	$5\frac{1}{2}$	$1\frac{1}{4}$	0.004
D	54	6	7	$3\frac{1}{8}$	$1\frac{1}{4}$	0.005
E	216	14	28	$9\frac{1}{4}$	6	0.006

The table above lists the physical characteristics of five experimental motors. Figure 3 shows the static pull-in and pull-out torque vs. field current for motor D. These torques would have been considerably higher if the stator slots had been deeper. The rather shallow slots limited the number of field windings that could be placed on the stator poles. The curves show that the iron was not saturated, so that maximum torque was not reached. Notice that the pull-in torque, which is the operating torque of the motor, closely approaches the pull-out or maximum torque for this winding and the specified field current values. The pull-in torque is based on $\frac{1}{3}$ -rotor-tooth overlap of the associated stator teeth. This is not usually the case, since the one-way lock tends to hold the rotor in the most advanced position. Another factor limiting torque is that the rotor was milled from SAE 10-18 cold-rolled steel—not an especially good magnetic material. The stator was assembled from commercial motor laminations, dimensionally altered to meet the needs of the stepping motor.

Figure 4 shows the relationship between pull-out torque and field current for motors A, B, and C. Motors B and C are only beginning to reach saturation, and motor A is clearly not saturated. It is interesting that all three motors approach a torque

of about 130 in.-lb for field currents of a little more than 6 amps, even though the motors vary considerably in size.

Torque vs. rotor-tooth overlap is shown in Figure 5. Although the two upper curves are drawn as straight lines, they would probably be more accurate if curved concave downward slightly. As expected, the curves show that torque increases as the rotor is displaced from the zero-torque in-register position. Tests show that maximum torque is obtained when the rotor teeth overlap the stator teeth about 10 percent of a tooth width.

Figure 6 shows dynamic breakdown torque vs. speed for stepping motor C. Field current was $\frac{1}{2}$ normal, and breaking torque was applied at various speeds until the motor broke down. Torque is fairly constant with increasing speed.

The largest unit constructed to date, motor E, is capable of delivering 3,000 in.-lb of torque. Figure 7 shows the pull-in and pull-out torque vs. field current for this unit.

To determine the possible acceleration rates of the stepping motors, the time interval required for a rotor phase to move from a stationary position of $\frac{1}{3}$ -rotor-tooth overlap to an in-register position relative to the stator teeth was measured using normal field current. Results showed that the snap-in time of

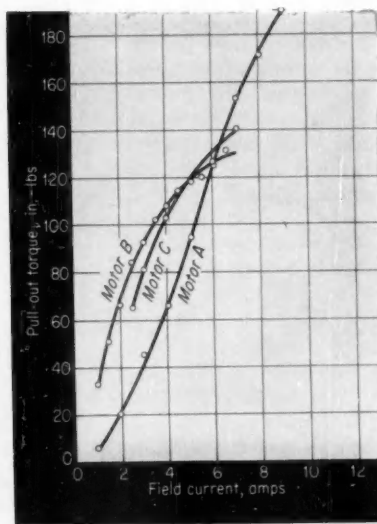
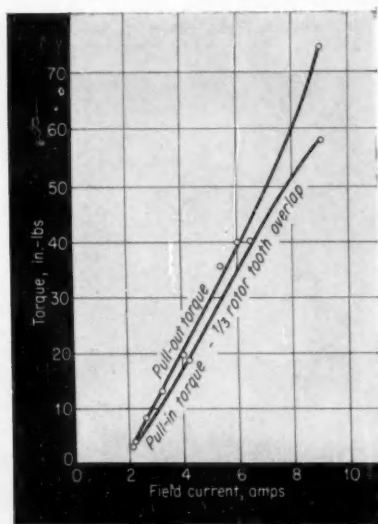


FIG. 3. (left) Pull-in and pull-out static torque vs. field current for 54-pole motor D.

FIG. 4. Pull-out torque for three of the motors listed in table above.

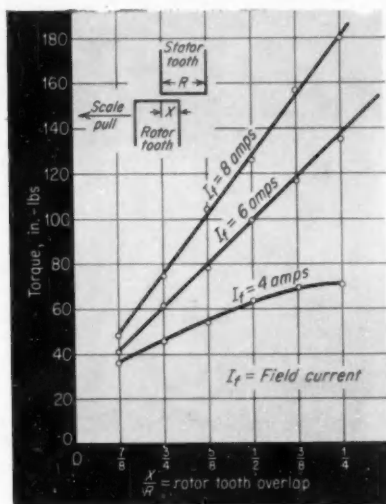


FIG. 5. Torque vs. rotor-tooth overlap for various field currents, motor A.

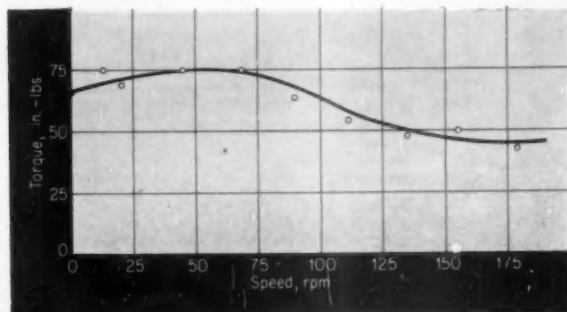


FIG. 6. (top) Dynamic breakdown torque vs. speed for motor C. Field current is $\frac{1}{2}$ rated value of 1.05 amps. Rated torque value of motor is 200 in.-lb.

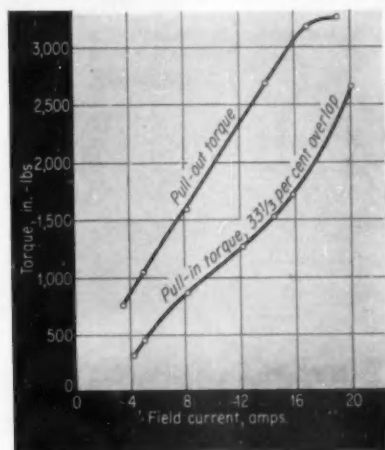


FIG. 7. Pull-in and pull-out torque for motor E rated at 3,000 in.-lb.

the various motors varied from 1/70 to 1/100 sec; however, this time interval can be reduced by increasing field strength and reducing rotor inertia.

Reliability tests were performed on motor C by punching an endless tape several feet long and reading it in a photocell sensor which delivered the pulse signals to the phase-control thyatrons. The tape perforations were programmed to accelerate the motor from zero speed to a stepping rate of 12,000 steps per minute in about four steps. The tape then caused the motor to decelerate to zero speed in the same number of steps. Tape speed was chosen so that the motor accelerated from standstill to the 12,000 steps per minute rate for half a revolution or more, and then back to zero speed, all within $\frac{1}{2}$ sec. The tape was repeated more than 3,000 times, representing approximately 350,000 steps. By matching marks on the casing and brake wheel it was verified that not one step was missed, indicating that this motor is reliable and highly accurate.

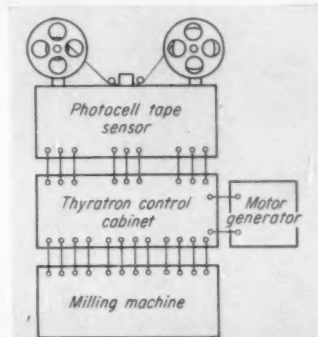
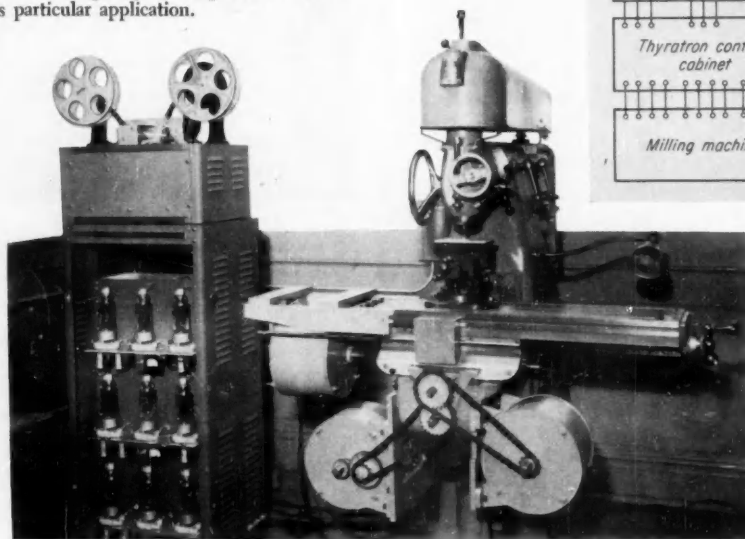
Since no feedback path is required, and the one-way brake prevents hunting, this type of motor should be a useful tool in a large variety of automatic control systems. Note, however, that the unit is an incremental device, in that there is no discrete indication of angular position and every new position is located a given number of steps from some previous known position. Thus, missed counts are cumulative unless accidentally compensated by an equal number of missed counts while traveling in the opposite direction.

Using the stepping motors

These stepping motors will respond to any source of pulses where the frequency of the pulses is proportional to desired motor speed, and the number of pulses is proportional to desired angular displacement. Such a source might be a digital computer, digital controller, recorded information from a storage medium, or a simple commutator device. Pulse amplification is required for the large motors discussed here, but smaller instrument-type motors operating on the same principle might be driven directly from contactors.

Figure 8A shows a small vertical miller on which the table vertical motion and two horizontal motions are controlled by three stepping motors through the machine's conventional lead screws. The input to the system is punched film read by a photocell tape sensor. Amplified photocell output fires the three banks of phase-control thyatrons, and drives the stepping motors, Figure 8B. The system uses a total of 20 tubes. Three-dimensional contouring can be done to an accuracy of 0.001 in. with the gear ratios and stepping motors used. Special anti-backlash devices counteract the effect of chain transmissions on this experimental model to maintain accuracy. Simple shapes and contours can be programmed manually by using a counting device while punching the tape. Complex shapes can be programmed by preparing the tape on a general-purpose computer³. The motor requirements for this system

FIG. 8. Tape-controlled milling machine uses stepping motors to position table for three-dimensional contour milling. Motors were originally developed to answer the need of this particular application.



are treated in more detail in the section that follows on selecting motors.

A prime advantage of this essentially simple system is that the motors behave as though electrically geared to the coordinating tape, cards, or other record. There is no overtravel or hunting, and motor speed is inversely proportional to the spacing of the controlling holes or spots. Direction is determined by means of a separate channel or a reversal of the order of placing the spots. Cuts made on this milling machine with a table movement of 0.001 to 0.002 in. per step do not show step ridges because the motors do not actually come to rest between steps.

A simple circuit for controlling two stepping motors from a contact-type tape-sensing device is shown in Figure 9. Motor direction is reversed by reversing the order of firing the thyratrons. Note the reversal in the bottom three rows of the tape which control the cross-feed motor. Extinguishing condensers snuff out the fired thyatron when any other thyatron is fired. The motors are always under controlled power and never float.

When the tape calls for a motor reversal, the one-way brake must also be reversed. The brake solenoids may be controlled by separate tape channels or actuated by relays responsive to the sequence of phase energization. Both systems have been used successfully.

The basic system of Figure 9, or a more sophisticated one using photoelectric or magnetic tape sensing, can be used for many things besides two-dimensional contouring. For example, there are many applications that require the accurate selection of discrete points in a plane, such as drilling, punching, welding, etc. Here the problem is to accurately locate the tool or other controlled device in two

dimensions, and the path between points is unimportant. Additional control channels and stepping motors can be used to select the proper drill or punch by rotating a turret.

Figure 10 shows another proposed application of tape-controlled stepping motors. In supersonic wind tunnels, the nozzle flow characteristics are controlled by varying the curvature of the flexible steel plates that comprise the throat section. One way to do this is to drive screw jacks by stepping motors programmed by tape to give the correct throat curvature. The desired positioning accuracy can be designed in by so selecting the gear ratio that one step of the given motor corresponds to less than the allowable tolerance. This system permits various curvatures to be selected by merely inserting a new tape, and makes sure that the plates are not overstressed by bending the plate unevenly, which might occur if the jacks were controlled manually. Other wind tunnel characteristics can also be controlled; i.e., pressure, temperature, or flow can be regulated by setting or controlling valve position.

Probably the broadest range of applications will be those in which the stepping motor is governed from a commutator or a simple switching network. Figure 11 shows a simple commutator circuit, such as might be used to control or to indicate angular position remotely. No feedback path is required. In this unit, the commutator rotates relative to the three grid-connected brushes. The equally-spaced contact bars are connected to the slip ring and to the positive side of the line through current-limiting resistor R_c . Rotating the commutator will cause the thyratrons to fire in a sequence depending on the direction the commutator is moved. A tube fires when its normal negative bias is canceled or

exceeded by the positive potential drop caused by current flowing through one of the resistors R_1 , R_2 , or R_3 . As before, the extinguishing condensers cut off a fired tube when the next one is fired. Transistor or magnetic amplifiers could be used instead of the thyratrons.

The brake must be reversed when the direction of rotation is reversed. The brake solenoid may be actuated by a slipping contact, frictionally driven by the commutator. The contact is held open when the commutator is turned in one direction, and closed when the commutator is reversed. As an alternative, a small self-synchronous motor or biased transformers can automatically determine when the brake-reversing solenoid should be energized.

There are innumerable applications of this technique, but it might be interesting to examine one for which the digital stepping motor is particularly well suited. In the remote operation of unattended gas or oil pipeline pumping stations, the speed of the oil pump or the output pressure of the compressor is changed by changing the set-point of a controller located at the remote station. This is currently done by digitally telemetering the new set-point to the remote station, where it is converted into an analog signal and used as the input command to a local servo that repositions the set-point

adjusting device as required. By using a small instrument-type stepping motor instead of the servo, the digitally telemetered information can be used directly without intermediate conversion. Many other possibilities suggest themselves.

HOW TO SELECT A MOTOR

Selecting a motor requires matching motor characteristics to system characteristics, and then making sure that a proper signal source is available. Figure 12 shows a general speed-torque curve for a typical stepping motor. The constant torque characteristic dictates that a stepping motor must be operated at close to its maximum speed if maximum power is to be delivered. For example, if a torque of 20 in.-lb is required at 10 rpm, a 20 in.-lb motor could directly drive the load at 10 rpm or a 2 in.-lb motor could be operated at 100 rpm and geared down 10 to 1. In the latter instance, the same horsepower is obtained from a much smaller motor.

Stepping motor resolution and speed are inter-related. As shown in Figure 13, the pulsing rate times the motion per pulse equals the velocity of motion. Consider the 50,000-pulse-per-minute curve—if a motion per step of 0.01 in. is required, the linear velocity is 500 in. per minute, but if a motion per step of 0.005 in. is required instead, the

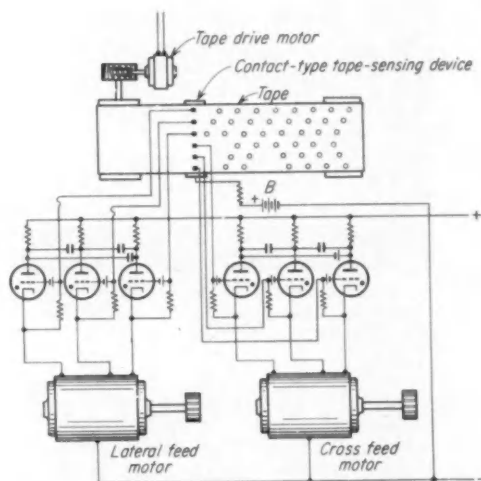
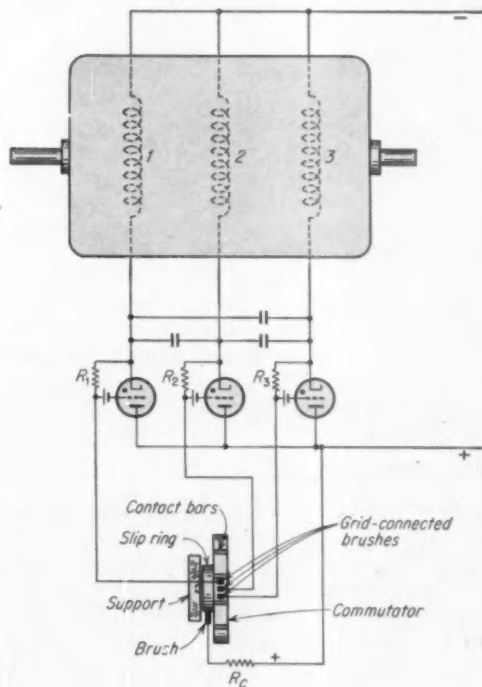
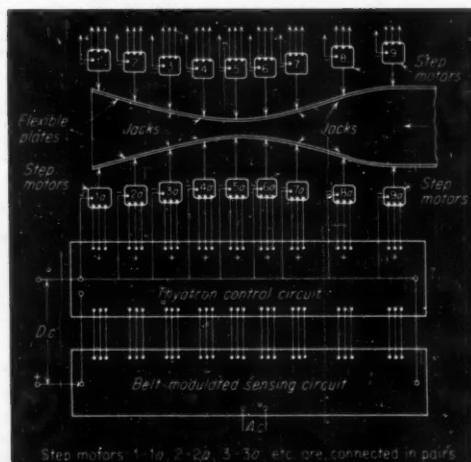


FIG. 9. (left) Simple tape-programming unit for two stepping motors.

FIG. 10. (bottom) Tape-programmed motors for wind-tunnel throat plates.

FIG. 11. Pulsing motor commutator.



Step motors 1-1a, 2-2a, 3-3a, etc. are connected in pairs

velocity reduces to 250 in. per minute. For a given resolution on the 25,000-pulse-per-minute curve, the velocity is one-half that obtained for the same resolution on the 50,000-pulse-per-minute curve.

Duty-cycle requirements

Load specifications and performance requirements are needed to select a motor. The load usually consists of three components: static and running frictional resistance, the inertia or mass of the moving parts, and the operational load or resisting force. The motor must be able to deliver sufficient torque to overcome the maximum combination of these three load components. From information gathered on the individual torque components, the duty cycle can be plotted as a curve of speed or position vs. time. From this operational cycle the maximum positioning accuracy and the maximum torque-speed combination can be obtained.

To find a motor that will handle a given cycle, examine the torque-speed and horsepower-speed curves for a series of stepping motors, Figures 12 and 14. Tentatively choose the smallest and most economical motor size that fits the maximum power requirements. Then consider the required positional accuracy and speed in the light of the maximum pulsing rate. Assume the motor to be considered has the characteristics shown in Figures 12, 13, and 14, and that the maximum power required for the cycle is represented by point A on Figure 14. Then if the accuracy requirements indicate that the resolution must be 0.007 in. per pulse, and N_A equals 50,000 pulses per minute, the maximum attainable velocity is 350 in. per minute.

Choosing a signal source

Assuming that thyristors are used as the output amplifier to the stepping motors, the signal pulses to the grid should have the following characteristics:

- ▶ approximately 120 volts
- ▶ duration of between 10 and 50 microsec
- ▶ square waveshape (not a rigid requirement)

As pointed out previously, the signal pulses will normally originate from recorded information, a commutator, or some other source of digital data. This information is already in digital form, and need only be amplified to fire the thyristors (or any other power amplifying medium that may be used). Where the original signal is in analog form, such as the output of a transducer, it must be converted to a string of pulses before it can be amplified to fire the thyristors.

Sizing the milling machine motors

Figure 15 shows experimental data accumulated by traversing the table of the milling machine. Row A1 includes data on frictional resistance only, without load, and row A2 includes the effect of a specified cutting load. The load consisted of cutting a slot $\frac{1}{4}$ in. deep and $\frac{1}{2}$ in. wide in wrought aluminum

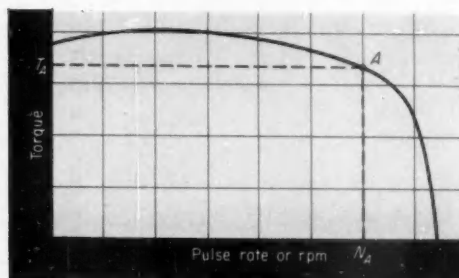


FIG. 12. Typical stepping motor torque-speed curve. Torque is approximately constant.

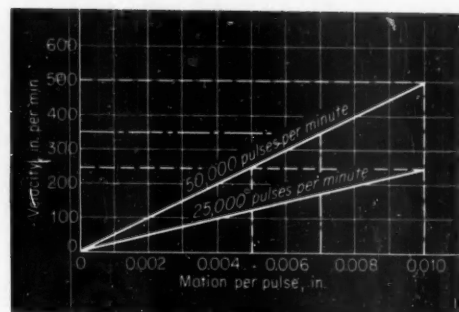


FIG. 13. Velocity vs. motion per pulse for different pulse rates.

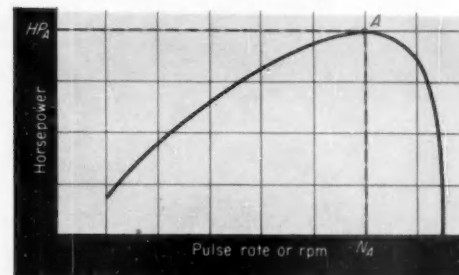


FIG. 14. Typical horsepower-speed curve. Constant torque characteristic means that power increases almost linearly with speed.

plate at a rate of 3 in. per minute. Running torque was obtained for only one speed (30 rpm at the feed screw, to which motor is directly connected); in general the running torque should be measured over the whole range of desired speeds.

To determine a duty cycle, program the X and Y motions of the table to cut a 6-in. circular groove, $\frac{1}{4}$ in. deep and $\frac{1}{2}$ in. wide. Only the X motion is treated here. A general procedure for finding the maximum accelerating torque from the distance-time duty cycle is to graphically differentiate the distance-time curve twice. Figure 6 shows this for the specified cycle. Note that the acceleration is maximum at the starting position. Motor acceleration can be derived from milling-machine-table linear acceleration once it is noted that 10 turns of the screw yield 1 in. of table motion. The mass of the table can

be converted to a proportional inertial load at the motor as indicated in the calculations. Thus the torque-time curve has the same shape as the linear acceleration curve, and either can be used by selecting the proper ordinate units. The total-torque-versus-time curve can now be obtained by adding to the accelerating torque, the static and running frictional torques, and the load torque for the various cutting velocities.

For this particular application the maximum torque is the starting frictional torque. The load and running frictional torques at this cutting velocity are smaller, and the accelerating torque is practically negligible. Thus the motor can be chosen to meet the starting torque requirements.

For the general case, however, it is necessary to determine the power required throughout the duty cycle by plotting the product of torque times velocity against time. Thus the maximum power point might occur anywhere in the cycle.

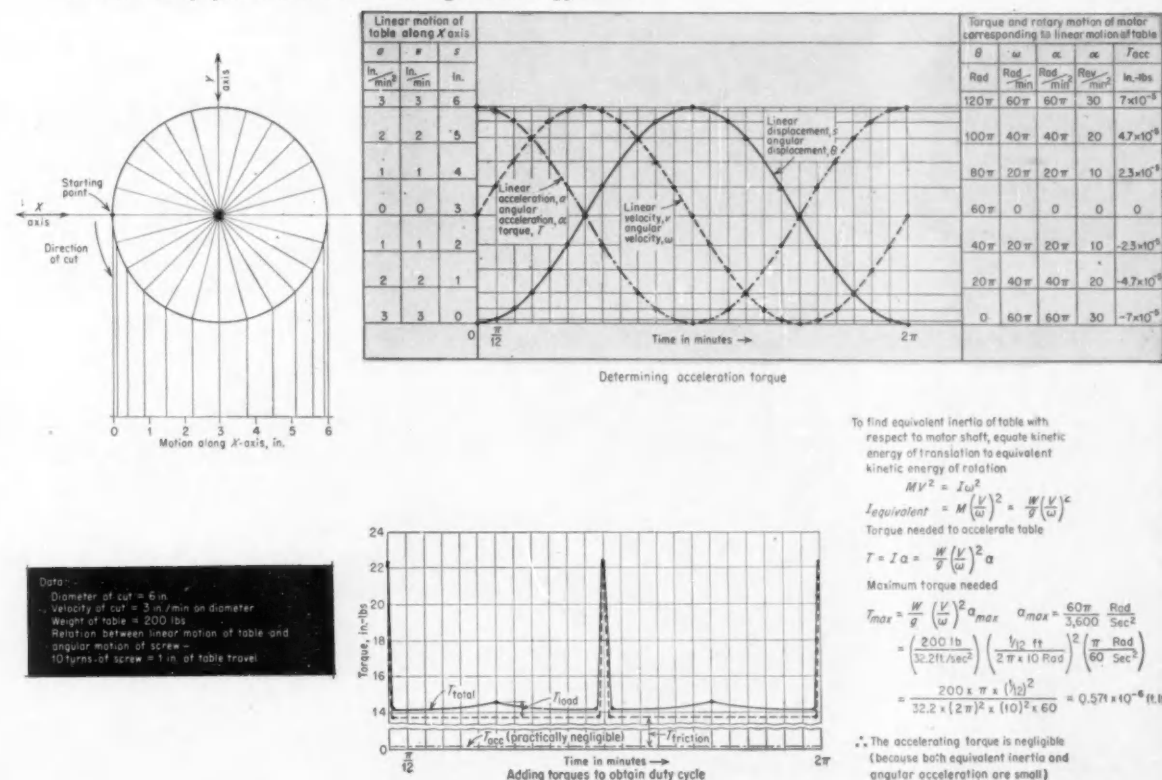
The torque capabilities of motor C easily satisfy the torque requirements of the system. Now determine the resolution of the system, or table motion per pulse.

$$\text{Table motion per pulse} = \frac{\text{motion of table per screw revolution}}{\text{number of motor poles}}$$

$$\text{Table motion per pulse} = \frac{0.1}{108} = 0.00092 \text{ in.}$$

And calculate the maximum table velocity for a pulse rate of 20,000 pulses per minute.

FIG. 16. Duty-cycle calculations for milling machine application.



Reading	Measured torque, in.-lbs		Motor speed, rpm
	Static	Running	
A1	22.15	13.75	30
A2	22.23	14.50	30

A1 - no load
 A2 - cutting $\frac{1}{2}$ in. \times $\frac{1}{4}$ in. slot

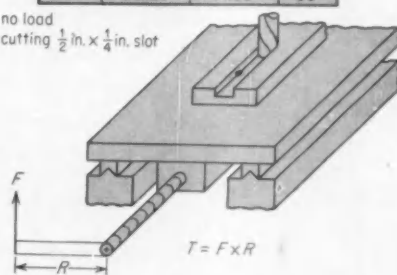


FIG. 15. Measured frictional and load torques for milling-machine application.

$$V_{\text{max}} = 0.1 \frac{20,000}{180} = 19.8 \text{ in. per min}$$

This is far in excess of the maximum speed requirements. If desired, smaller motions per step with velocities still within the allowable limit could be achieved by gearing the motor to the leadscrew. In any event, the experimental motors used on the milling machine are far more powerful than required.

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2. MEASURE POSITION DIGITALLY, Waldo H. Kliever, "Control Engineering", November 1956.
3. AUTOMATIC PROGRAMMING OF NUMERICALLY-CONTROLLED MACHINE TOOLS, Arnold Siegel, "Control Engineering", October 1956.

THE GIST: When a linear potentiometer excited with an ac voltage drives a resistive load through shielded wire or cable, the output voltage consists of in-phase and quadrature components, both of which can influence electronic computation. The departure from linearity of the in-phase component causes actual computing errors, while the quadrature voltage may broaden the null in a calculation or saturate the amplifier in a following servo.

The three references covered techniques for reducing resistive loading errors by using taps and shunting resistors. In an analogous way, quadrature errors can be reduced by means of taps and shunting capacitors. Tap locations are determined by drawing approximating straight lines on the quadrature plot. Then shunting capacitor values are calculated by using these tap locations and the known slopes of the approximating straight lines. To show the method the single-tap case is treated in detail. The general formula for many taps is then derived and applied to several two-tap designs, which are useful in reducing the quadrature voltage output of multi-turn pots that have a capacitive load. Quadrature reduction factors vary from 6 to 60, depending on the tap design.

How to Phase-Compensate Loaded Potentiometers

JACK GILBERT, Norden-Ketay Corp., Norden Laboratories Div.

It was shown in Reference 1 that the in-phase or linearity errors caused by a high resistance load, R_0 , can be reduced by using a single tap, X_0 , and a compensating resistor, b . Figure 1A shows the circuit and the optimum values of X_0 and b . The resulting linearity error curve for this design is shown in Figure 2: in-phase errors are reduced by a factor greater than seven. By connecting a phase-compensating capacitor, C_0 , across resistor b , Figure 1B, quadrature voltage can be reduced by the same amount. It is only necessary to assume that the lumped terminal capacity of the potentiometer is much smaller than that of the load capacity, C_0 , or that the potentiometer has negligible phase shift.

For resistive-loading compensation, it was shown that the voltage ratio error for R_0/R much greater than one is given approximately by:

$$\frac{EX - E_0}{E} = \epsilon = \frac{X^2(1 - X)}{R_0/R} \quad (1)$$

where ϵ = voltage ratio error and the remainder of the nomenclature is given in Figure 1A. But for capacitive-

loading compensation, Figure 1B, the actual load impedance is

$$Z_0 = R_0/(1 + j\omega R_0 C_0) \quad (2)$$

Replace R_0/R by Z_0/R (much greater than one). Then

$$E_0 = E_i + jE_q \quad \text{and} \quad \epsilon = \epsilon_i + j\epsilon_q$$

Combining Equations 1 and 2 gives:

$$\epsilon_i + j\epsilon_q = \frac{X^2(1 - X)(1 + j\omega R_0 C_0)}{R_0/R}$$

Therefore, the in-phase error is

$$\epsilon_i = \frac{X^2(1 - X)}{R_0/R} \quad (3)$$

and the quadrature ratio error is

$$\epsilon_q = (X^2)(1 - X)\omega R C_0 \quad (4)$$

The quadrature voltage, E_q , is

$$E_q = E\epsilon_q = \omega R C_0 E(X^2)(1 - X) \quad (5)$$

The maximum value of ϵ_q occurs at $X = \frac{2}{3}$ and is

$$\epsilon_{qm} = 0.148\omega R C_0$$

Consequently,

$$E_{qm} = 0.148E\omega R C_0 \quad (6)$$

FIG. 1.

Single-tap compensating designs: A shows compensation for resistive loading, and B shows analogous quadrature compensation for capacitive loading.

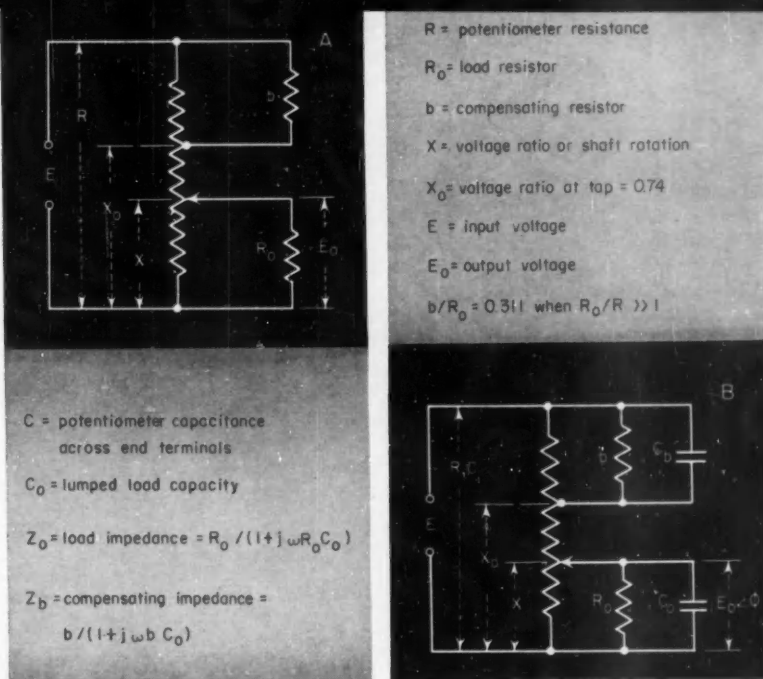
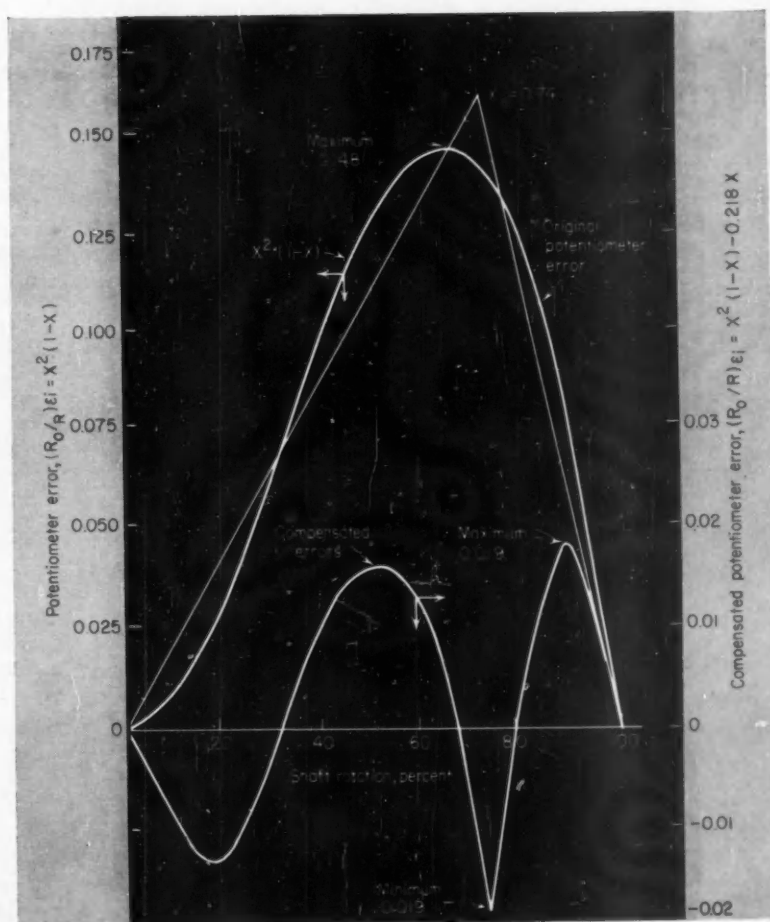


FIG. 2.

Shaft rotation versus original and compensated in-phase potentiometer errors. If inherent potentiometer phase shift is negligible, the original and compensated quadrature error curves for a capacitive-loaded, capacitive-compensated pot have the same shape as those shown here.



Equation 6 gives the maximum quadrature voltage in the output of a capacitive-loaded linear potentiometer. If $R = 10,000$ ohms, $\omega = 2,700$ rad per sec, $C_0 = 1,000$ mmf of cable, and $E = 20$ volts rms; then $E_{qm} = 80$ millivolts. Any increase in $E\omega RC_0$ is reflected in a direct increase of quadrature voltage.

Single-tap compensation

Equations 1, 3, 4, and 5 show that the linearity errors and the quadrature voltage are identically dependent on shaft rotation. Hence, the analytical expressions for linearity error in the presence of tap X_0 and compensating resistor b should apply to the quadrature error in the presence of tap X_0 and capacitor C_0 . Reference 1 showed that the linearity error after loading compensation has been applied is equal to the original error minus the corrective effect of the compensating resistor, or

$$\epsilon = \frac{X^2(1-X)}{R_0/R} - \frac{X(1-X_0)^2}{b/R} \quad (7)$$

where $0 < X < X_0$. Substitute in this expression to include the effect of the compensating capacitor as follows:

$$\begin{aligned} \text{replace } b \text{ by } & b/(1+j\omega bC_0) = Z_b \\ \text{replace } R_0/R \text{ by } & R_0/R(1+j\omega R_0C_0) = Z_0/R \\ \text{and let } & R_0C_0 = bC_0 \\ \text{Then,} & \\ \epsilon = \epsilon_i + j\epsilon_q = & \left[\frac{X^2(1-X)}{R_0/R} - \frac{X(1-X_0)^2}{b/R} \right] (1+j\omega R_0C_0) \quad (8) \end{aligned}$$

Separating the in-phase and quadrature errors, and letting $u = b/R_0$,

$$\frac{R_0}{R} \epsilon_i = X^2(1-X) - X(1-X_0)^2/u \quad (9)$$

and

$$\frac{R_0}{R} \epsilon_q = \omega R_0C_0 [X^2(1-X) - X(1-X_0)^2/u] \quad (10)$$

Therefore,

$$E_q = \omega R C_0 E [X^2(1-X) - X(1-X_0)^2/u] \quad (11)$$

Equations 9 and 11 describe the in-phase and quadrature errors of a compensated potentiometer with small phase shift, where the time constant of the compensating network, bC_0 , equals the time constant of the load, R_0C_0 . The reduced in-phase error voltages, which have identical form for potentiometers with negligible phase shift, are plotted on Figure 2, together with the original error voltages for comparison.

Reference 3 showed that the optimum values of X_0 , and the shunting resistor, b , for the resistive-compensated single-tap design were 0.74 and 0.311 R_0 , respectively. And since

$$bC_0 = R_0C_0 = 0.311R_0C_0 \quad (12)$$

then

$$\frac{C_b}{C_0} = \frac{1}{0.311} = 3.22 \quad (13)$$

Applying these design constants to the 10,000-ohm pot discussed previously, it is experimentally found that the compensated quadrature plot as well as the original quadrature plot are practically identical to the in-phase plots in Figure 2, and the 80-millivolt maximum quadrature figure is reduced to about 11 millivolts.

This shows that all of the compensated designs for high load ratio discussed in Reference 1 can be extended to include the capacity load condition, provided $bC_0 = R_0C_0$. Table I summarizes the results for several load ratios. (If there is a dropping resistor, R_s , in series with the main potentiometer winding, a shunt capacitor C_s must be added such that $R_sC_s = RC_0$. This assures zero phase error at the upper end of the potentiometer.)

The general procedure

Reference 3 showed that there is a simple formula relating the values of the shunting resistors to the tap points and the straight-line slopes drawn on the voltage ratio error curve. This relationship can be expressed as:

$$\frac{R_i}{R} = \frac{X_j - X_i}{S' - S'_i} \quad (14)$$

where

R_i is the desired shunting resistor

X_j and X_i are adjacent taps

S'_i is the slope of a given straight line drawn on the loading error curve

S' is the maximum positive slope of any of the straight lines

It can be shown that a similar relationship holds for values of shunting capacitors C_{bi} in terms of the tap points and straight-line slopes drawn on the quadrature plot (see Figure 3B for schematic).

Temporarily define

$$S'_i = \frac{E_{qi}}{E(\Delta X_i)}$$

where S'_i is the corresponding slope of a typical straight line drawn on a plot of quadrature ratio,

Table I—ONE-TAP COMPENSATED DESIGNS FOR VARIOUS LOAD RATIOS*

R_0/R	b/R_0	C_b/C_0	R_0/R	Maximum quadrature, E_{qm}/E	Quadrature reduction factor
∞ **	0	3.22	0	$0.019\omega RC_0$	7.8
over 10	0.311	3.22	0.019	$0.019\omega RC_0$	7.8
5	0.311	~3.4	0.022	~ $0.022\omega RC_0$	~6.4
2	0.304	~3.8	0.024	~ $0.024\omega RC_0$	~5.0

*Source impedance = 0
 ** Open-circuit potentiometer
 $X_0 = 0.74$ fixed
 $C_0 > C$

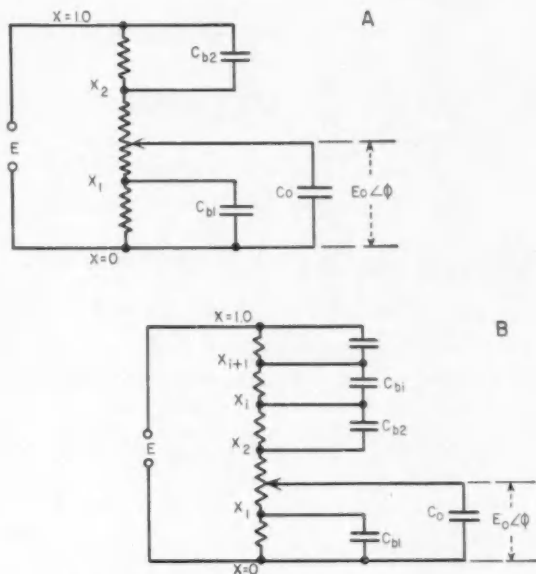


FIG. 3. Two-tap, A, and multi-tap, B, designs for capacitive-compensated pots.

E_q/E . Replacing R_i by $1/\omega C_{bi}$ as in the one-tap design, Equation 14 becomes

$$\frac{1}{j\omega RC_{bi}} = \frac{\Delta X_i}{j(S' - S'_i)} \quad (15)$$

Then

$$C_{bi} = \frac{S' - S'_i}{(\Delta X_i)\omega R}$$

Since the measured quadrature plots are generally given directly in terms of absolute voltage, replace S'_i by S_i/E and S' by S/E . Thus,

$$C_{bi} = \frac{S_i - S}{(\Delta X_i)\omega R E} \quad (16)$$

where

C_{bi} is the desired value of the shunt capacitor
 S_i is the slope of a given straight line drawn on the measured or theoretical quadrature voltage plot

S is the maximum negative slope of any line drawn on that plot

ΔX_i is the percent rotation difference between adjacent taps X_j and X_i

E is the low impedance exciting voltage

(The sign is reversed in the numerator between Equations 15 and 16 because the slopes in Equation 16 refer to the actual quadrature voltage, not the error quadrature voltage.)

For the cases of high load ratio and potentiometers with negligible phase shift, the same quadrature voltage reduction can be obtained as was previously found for the analogous resistive loading case. For this condition, $R_i C_{bi} = R_0 C_0$, or the time constant of each compensation network equals the time constant of the load.

Since the components R_i and C_{bi} depend only on

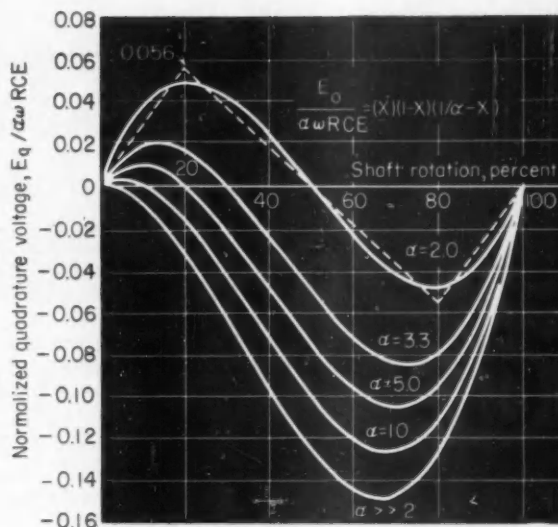


FIG. 4. Quadrature functions of a ten-turn potentiometer.

the load constants, they need not be mounted on the potentiometer, but can be fixed in the computer wiring and connected to the proper taps on the potentiometer.

If the quadrature plots differ functionally from the linearity curves (for example, where a potentiometer has substantial phase shift) the taps must be chosen separately for optimum reduction of each type error. However, the equal time-constant criterion quite often gives sufficient quadrature reduction.

Two-tap compensation

The general procedure will be applied to a ten-turn potentiometer with conducting core. The quadrature behavior of this type potentiometer is of current interest and provides a variety of compensation designs.

It can be shown that the quadrature voltage plot of a ten-turn potentiometer is given approximately by the expression

$$\frac{E_q}{E} = \omega RC \alpha [X(1 - X)(1/\alpha - X)] \quad (17)$$

Where

$$\alpha = (2C + C_0)/C$$

R = overall potentiometer resistance
 C = potentiometer lumped capacitance

The expression for $E_q/aE\omega RC$ is plotted in Figure 4 for various values of α . For $C_0 = 0$ and $\alpha = 2$, the quadrature voltage plot is the symmetrical S-curve of the potentiometer alone. The equation of this curve is

$$\frac{E_q}{E\omega RC} = 2X(1 - X)(0.5 - X) \quad (18)$$

For C_0/C much greater than one, and for $1/\alpha$

approximately equal to zero, Equation 17 becomes

$$\frac{E_q}{E\omega RC} = -X^2\alpha(1-X) \quad (19)$$

or

$$\frac{E_q}{E} = -(2C + C_0)\omega RX^2(1-X) \quad (20)$$

Equation 20 is identical in form to Equation 5, except for the addition of the $2C$ term to C_0 , which accounts for the potentiometer's capacitance. Thus, the compensation designs for Equation 20 follow directly from the previous discussion. On the other hand, no one tap and compensating capacitor will reduce the maximum quadrature points of Equation 18.

As was pointed out, the plot of Equation 18 is the symmetrical S-curve of the potentiometer alone. Figure 5 shows the measured curve for a potentiometer with $R=10,000$ ohms, $\omega=2,760$ rad per sec, and $E=20$ volts rms. The approximating straight lines indicate that taps are required at about $X_1=0.20$ and $X_2=0.80$.

Theoretically, for the symmetrical S-curve of Figure 4 where $a=2$,

$$S_1 = S_2 = \frac{+E_{qm} - 0}{0.2 - 0} = + \frac{E_{qm}}{0.2}$$

$$S = \frac{-E_{qm} - E_{qm}}{0.8 - 0.2} = - \frac{E_{qm}}{0.3}$$

$$\Delta X_1 = \Delta X_2 = 0.20$$

and

$$E_{qm} = 2\omega RCE(0.048 + 0.006) = 2(0.056)\omega RCE$$

where E_{qm} is the straight-line value.

Substituting these values in Equation 16 gives

$$C_{b1} = C_{b2} = \frac{2(0.056)}{0.2} \frac{\omega RCE}{\omega RE} \left[\frac{1}{0.2} + \frac{2}{0.6} \right] = 4.67C \quad (21)$$

Thus, the compensating capacitor is theoretically equal to a constant times the lumped capacity across the end terminals of the pot. For convenience, two 1,000-mmF capacitors were used for C_{b1} and C_{b2} (assuming $C=210$ mmF; then, according to Equation 21: $C_{b1} = C_{b2} = 980$ mmF). Experiments showed that it was necessary to pad C_{b1} up to 1,045 mmF.

For comparison, calculate C_{b1} and C_{b2} using quadrature and slope values read from the actual quadrature plot of Figure 5. From the curve

$$S_1 = \frac{0.0133}{0.2} = 0.0667 \quad S_2 = \frac{0.0126}{0.2} = 0.0630$$

$$S = \frac{-(0.0125 + 0.0133)}{0.6} = -0.043$$

$$\Delta X_1 = \Delta X_2 = 0.20$$

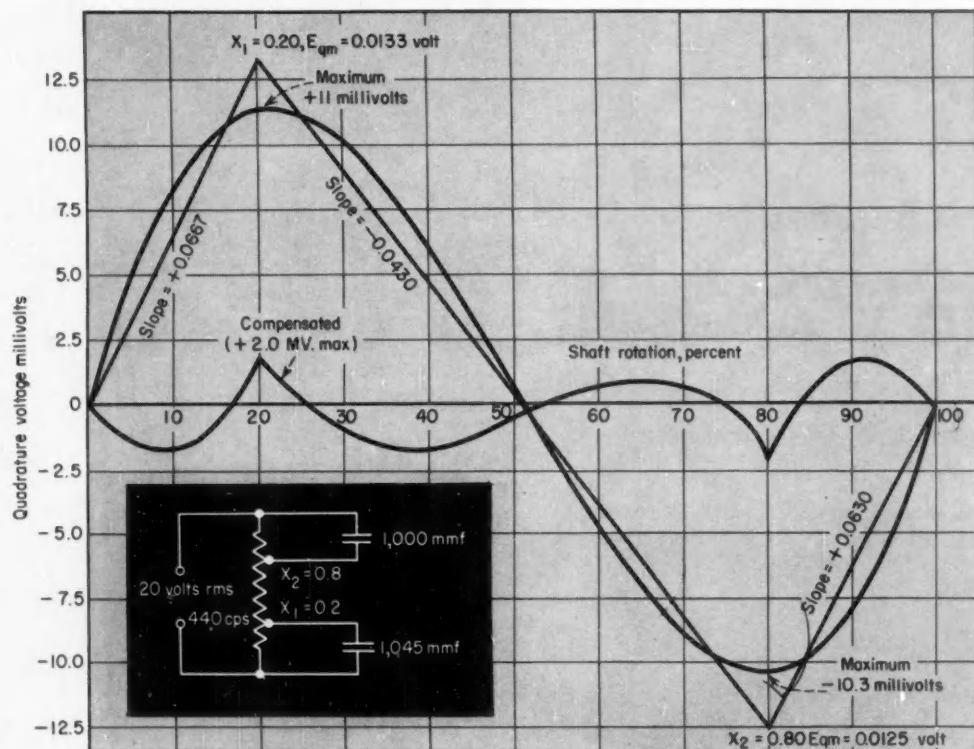


FIG. 5. Original and compensated quadrature error curves for two-tap compensated ten-turn potentiometer. Potentiometer resistance is 10,000 ohms, and terminal capacitance is about 210 mmF.

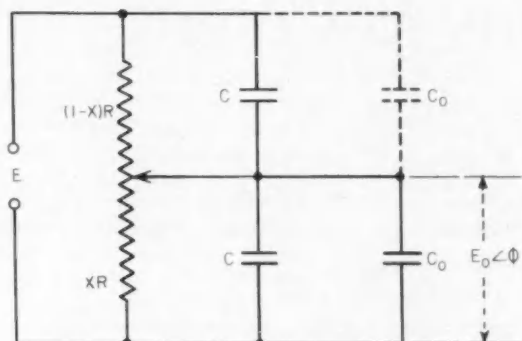


FIG. 6. Simplified equivalent circuit of ten-turn pot.

Substitution of these values in Equation 16 gives

$$C_{b1} = \frac{(0.0667 + 0.0430)}{(0.20)(2,760)(10,000)(20)} = 1,030 \text{ mmf}$$

$$C_{b2} = \frac{(0.0630 + 0.0430)}{(0.20)(2,760)(10,000)(20)} = 960 \text{ mmf}$$

These values average a few percent lower than the experimental values used, which were not necessarily optimum. However, the maximum quadrature was reduced by a factor of about five, and the agreement with theory was within the experimental tolerances on E , ω , R , and C , and the quadrature measurement technique.

Under a finite load C_0 , the quadrature plot becomes asymmetrical, crossing zero to the left of $X = 0.5$. This curve can be restored to the symmetrical S-condition by connecting an equal capacity load, C_0 , between the slider and the upper end terminal as can be seen from the equivalent circuit of Figure 6. It can be shown that the resulting quadrature is the same function of X except that the effective capacitance of the potentiometer, C , is replaced by $(C + C_0)$. Thus, the theoretical compensating capacitor becomes

$$C_b = 4.67(C + C_0)$$

and the maximum resulting quadrature voltage ratio is

$$E_{qm}/E = 0.016\omega R(C + C_0) \quad (22)$$

Again, the taps can be specified in advance regardless of the capacity load to be used. The capacitors, C_{b1} , can be procured and connected after the load capacity C_0 has been determined. Using two taps, a quadrature reduction of from six to nine can be obtained for various values of α (see Table II).

Summarizing

Any potentiometer can be corrected for predictable quadrature functions of the output by using the proper number of taps and compensating capacitors. First draw the optimizing straight lines through the expected quadrature plot. The intersections of

Table II
ONE- AND TWO-TAP DESIGNS FOR TEN-TURN POTS

Load C_0	Taps		Compensating capacitor, C_b/C_0	Maximum quadrature, E_{qm}/E	Quadrature reduction factor
	X_1	X_2			
C	0.74	3.22	$\sim 0.019\omega RC_0$	~ 7.8
0	0.20	0.80	4.67	$\sim 0.016\omega RC_0$	~ 6.0
C_0^*	0.20	0.80	4.67	$\sim 0.016\omega R(C + C_0)$	$\sim 6.0-9.2$

* Connect additional equalizing capacitor equal to C_0 from slider to upper end of pot.

adjacent straight lines give the locations of the adjacent taps. The straight-line slopes, tap values, and circuit constants can be inserted in Equation 16 and the values of the various capacitors, C_{b1} , calculated. For capacitive-loaded pots with negligible phase shift, and multiturn potentiometers with conducting cores, the compensating designs can be predicted beforehand.

The compensating capacitors or resistors can remain fixed in the installation when they depend only on the load. When both the quadrature and linearity errors have the same functional dependence on shaft rotation (as in Equations 3 and 5), then the time constants of the individual compensating networks across adjacent taps are equal to each other and to the load constant R_0C_0 . If five taps are used for the quadrature curve of Equations 5 or 19, a reduction factor of about 60 is realized (see Reference 3).

EDITOR'S NOTE: Derivations of Equations 17 and 22 in this article are available to those readers who would like to delve into the background of the mathematics.

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ACKNOWLEDGEMENT: The author would like to thank Mr. E. R. Schlesinger for his helpful suggestions on all phases of the compensation problem, and Mr. Paul Rettenmeyer for his work on phase-shift measurements.

Applying Thyratrons to Control

Prompted by the increasing application in the control field of transistors as low-power amplifiers and thyratrons as high-power amplifiers, CONTROL ENGINEERING last October began what could be considered a three-article series with Herb Aronson's "Applying Transistors to Control". The second article in the series, by Jim Burnett, appears below.

In "Applying Thyratrons to Control", author Burnett presents a complete and up-to-date discussion of thyatron servos, which are turning in optimum performances in military and industrial applications. He describes the principles of their operation, shows how to control their output for motor and magnetic clutch loads, and details application procedures.

Next month Burnett will draw from actual applications in machine-tool, radar-antenna, guided-missile, and wind-tunnel control to demonstrate stabilization techniques for thyatron servos. His method, which uses ideal kinetic-energy damping (thus no velocity error), is an original contribution to control technology.

JAMES H. BURNETT, Electronics, Inc.

Unlike the two-electrode rectifier, the gas- or vapor-filled grid-control rectifier, or thyatron, has a grid which smoothly controls output power over the full range of values by drawing only microwatts of power. Thus thyratrons as high-gain amplifiers control loads up to several kilowatts.

Not only do thyratrons deliver controllable-magnitude ac or dc outputs, but the direction of load current flow can be reversed. Thus, they can supply power to ac or dc motors, control the motors' speeds or torques from zero to full-rated, and reverse their directions of rotation. As amplifiers, therefore, they are well-suited to power a servo motor.

Although thyratrons perform many other useful functions in industry, they will be treated here only as efficient and reliable power amplifiers for:

- ▶ driving high-power electric servo motors directly
- ▶ powering magnetic clutches and motor-generator fields for indirect control of even higher-power servos

THE THYRATRON'S PLACE IN CONTROL

Thyatron tubes are manufactured with anode current ratings ranging from a fraction of an ampere to approximately 25 amp. Thus, a 75-amp-load current can be controlled from a three-phase supply line. However, maximum tube ratings alone do not determine the practical power range for thyatron servo amplifiers. Several other factors are involved.

For loads up to 25 watts, high-vacuum tubes, transistors, and magnetic amplifiers are more efficient and simpler to use. Thyratrons find their most

effective use in the range between 25 watts and 5 kw. At the upper power limit the dynamic response is determined by the best available torque-to-inertia ratio of electric motors. Above a few horsepower the torque-to-inertia ratio of hydraulic motors is usually superior to the best available electric motors. This may justify use of hydraulic amplifiers and motors for applications needing fast response in higher-power servo systems.

The thyatron comes into its own again, however, in applications requiring field supply of motor-generators in the hundreds of horsepower, and excitation of magnetic couplings of tens of thousands of horsepower. Here it is used because of its efficient output forcing voltage, which minimizes the inherent inductive time delays of such power systems.

Thus, to sum up, thyratrons are most useful for directly driving a positioning servo load between 25 w and 5 kw. However, even for loads above 5 kw thyratrons can indirectly control the power driving the load. In many high-power servo applications, such as machine-tool control, the load is driven by the motor through a magnetic clutch and is connected and disconnected as the clutch is energized or deenergized. In such on-off applications, the motor continues to rotate at full speed, thus eliminating the problem of accelerating motor inertia. In other applications using eddy current magnetic clutches the motor also operates at full speed, but coupling between motor and load is controlled by the amount of power supplied to the clutch. The supplied power controls clutch slip and thus varies load speed and applied torque.

Amplifier considerations

In addition to thyatron amplifiers other types of amplifiers which the designer may consider include the motor-generator, magnetic, and high-vacuum. A sound engineering decision as to which is best for a particular application will be influenced by some or all of the following factors:

► **Speed of response**—If an ideal power amplifier and an ideal stabilizing means were provided (with no time delays introduced by either) the dynamic range of servo performance would still be limited by motor power available (once the friction load requirements were satisfied) to overcome motor and load inertia. In a system with a large ratio of reflected load inertia to motor inertia, increased motor power improves servo response. Thus, within broad limits the desired response performance is designable; it depends on how much penalty the designer is willing to pay, in terms of increased motor and amplifier power, for improved performance. Once the motor requirements have been determined, the designer chooses a practical power amplifier and stabilizing means with the smallest time delays.

In a thyatron amplifier the only inherent delay is a fraction of a cycle of the supply line frequency. For a half-wave single-phase circuit the maximum delay is one cycle, for full-wave single-phase it is one-half cycle, and for three-phase it is one-third of

a cycle. Thus, for the latter case the maximum lag is 0.0055 sec with a 60-cps supply line.

► **Size, weight, and cost**—Figure 1 shows typical values of thyatron servo amplifier size, weight, and material cost on a per-kilowatt basis. Separate curves show these values when anode transformers are included and when the thyatrons operate directly from the supply line. Cost figures include approximate 1956 direct materials costs for the following components: anode transformers, thyatrons, tube sockets, filament supply, grid circuits, circuit overload protection, and chassis.

► **Reliability**—Experience accumulated with thousands of carefully-engineered units indicates that tube life can be expected to exceed 10,000 hours operation, and that 20,000 hours is not unusual. A remarkable correlation exists between actual tube life and the care given to individual circuit design. By a simple in-service measurement of tube voltage drop, approach of end of life can be predicted and replacement made when the voltage drop increases to a predetermined value¹.

► **Efficiency**—Thyatron amplifier efficiency increases with an increase in anode voltage, since the filament losses are constant. The other principal power loss in a transformerless amplifier is caused by tube voltage drop, usually about 10 volts. The drop is independent of the load current, although its associated power loss is directly proportional to the output

FIG. 1. The approximate size, weight, and cost of half-wave thyatron positioning servo amplifiers have been plotted here, on a per-kilowatt basis, to give some concept of these important factors. Cost figures are based on approximate 1956 direct materials cost.

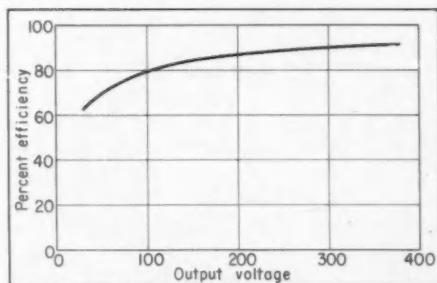
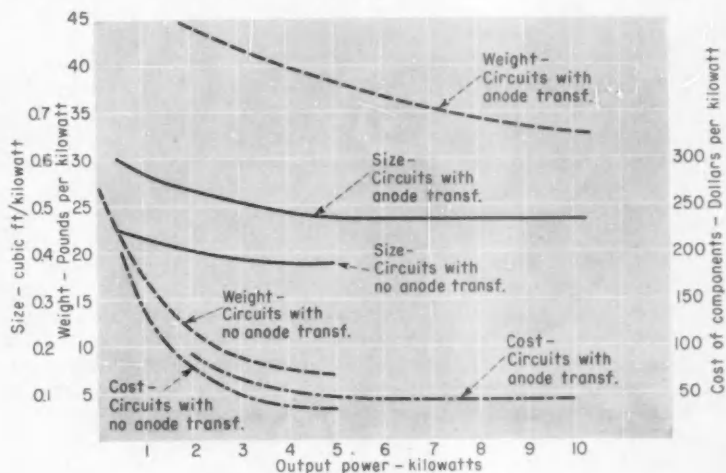
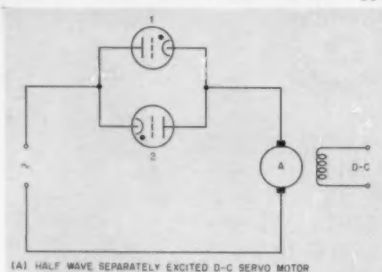
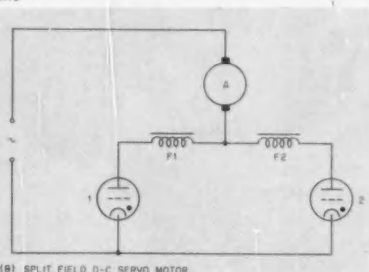


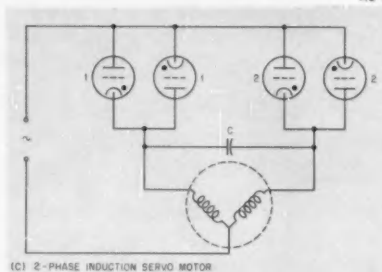
FIG. 2. The efficiency of a thyatron servo amplifier increases with an increase in load voltage. The plot shown is for a half-wave reversing servo amplifier capable of driving a 2-hp motor. Motor losses are not included in the plot.



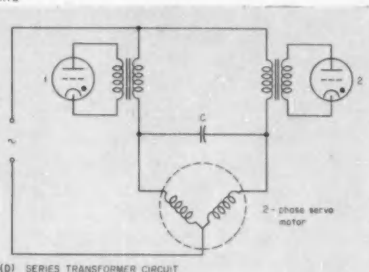
(A) HALF WAVE SEPARATELY EXCITED D-C SERVO MOTOR



(B) SPLIT FIELD D-C SERVO MOTOR



(C) 2-PHASE INDUCTION SERVO MOTOR



(D) SERIES TRANSFORMER CIRCUIT

FIG. 3. BASIC OUTPUT CIRCUITS FOR THYRATRON CONTROL OF DC AND AC SERVO MOTORS

current. Other amplifier losses include those due to iron and copper in the anode transformer (if one is used) and some relatively incidental ones in the grid circuitry and preamplifier. Figure 2 shows the approximate efficiency of a half-wave thyatron reversing servo amplifier operating at full load of 2 hp for various values of load voltage. The curve does not include motor losses.

THYRATRON BASICS

The usual gas- or vapor-filled thyatron is a triode, and thus contains within its envelope an anode (plate), a cathode (filament), and a grid. Unlike the usual high-vacuum triode, however, thyatrons usually are operated with ac, not dc, on the anode, particularly in servo applications. Thus, they conduct only during the positive half-cycle (with respect to the cathode) of the ac anode supply. Since the current flows only in one direction, thyatrons are half-wave rectifiers delivering pulsating dc.

In high-vacuum triodes the grid exercises continuous control over the tube's output, which thus can be increased or decreased at any time simply by increasing or decreasing the grid potential. In the case of thyatrons, however, a grid triggers conduction at some time in the positive half-cycle and conduction continues for the balance of that half-cycle. Once conduction starts the grid loses control, but at the end of each cycle the anode voltage returns to zero and conduction ceases. The average output voltage is controlled by shifting the time in each cycle, or firing angle, at which conduction starts, since the grid regains control once each cycle. A reliable grid control circuit is one of the most important design problems in thyatron applications.

Because there are various ways of connecting the outputs of thyatrons and controlling the firing angle of their grids, thyatrons are a most versatile control component. They can produce half-wave and full-

wave dc, reverse the direction of dc load current flow and hence change direction of motor rotation, and can produce a reversible-phase ac current to drive and reverse ac motors. Figure 3 shows some of the basic output circuits, and Reference 2 describes many other arrangements and variations for driving ac and dc motors. The magnitude and direction of load current flow determines the speed and direction of motor rotation. But it is the grid signal that determines the nature of the output current. Grid circuit control will be discussed in more detail under design procedures. Assuming that the appropriate grid control circuits are available, reversing and speed control of the dc and ac motors shown in Figure 3 operate as follows:

The speed and direction of a separately-excited dc servo motor depend on the magnitude and polarity of current flowing in the armature. In Figure 3A this control is obtained by the inverse-parallel connection of the thyatrons, where each operates as a half-wave rectifier. Tube 1 serves for the first half-cycle and tube 2 the second half-cycle. Thus tube 1 delivers dc current in one direction and tube 2 in the other. The net dc load current is the sum of the individual tube currents, taken over the whole cycle. Therefore, if tube 1 passes more current during its conducting half-cycle than tube 2 does during its half-cycle the motor will rotate in one direction. If conditions are reversed, the motor reverses too.

The speed and direction of a split field dc servo motor (Figure 3B) depend on which of two fields is energized. Thus current flows in F1 when tube 1 conducts and causes rotation in one direction; it flows in F2 when tube 2 conducts and the direction is reversed. In servo applications the grid signal depends on the servo's error signal. Thus, an error signal causes the appropriate field to be energized and rotates the motor to diminish the error.

Control of a two-phase induction servo motor

can be obtained in several ways, two of which will be described. The circuit in Figure 3C uses two sets of inverse-parallel connected thyratrons. Here the current through the windings must be ac, and the direction of rotation depends on which set of thyratrons passes more current. Consider the thyratrons at the left. Appropriate grid signals cause each tube to fire for an equal time during their conducting half-cycles, thus producing a controllable ac output. The other set operates similarly to directly energize the other winding and reverse direction.

A two-phase servo motor can be controlled and reversed with only two thyratrons (Figure 3D), but two series transformers are needed. Here a transformer is in series with each motor winding. The direction and speed of rotation depends on the relative voltage drops due to the reactance of each transformer secondary. When a thyatron conducts it reduces the primary reactance of its transformer, which is reflected into the secondary and hence increases the voltage applied to the motor.

DESIGNING AMPLIFIERS for controlling motors

In designing a thyatron servo amplifier as a main power supply, the following steps are carried out in the order given:

- ▶ selecting the motor type and size to drive the load with an acceptable speed of response
- ▶ designing the amplifier to deliver the power required to drive the motor
- ▶ designing the servo's error sensing circuit
- ▶ designing the grid control circuit
- ▶ designing required stabilization

Choice of a satisfactory grid circuit to meet the requirements of the particular application is the most critical step in thyatron amplifier design; therefore this point will be discussed first.

Grid circuit design

The basic problem in smooth proportional control of the load is conversion of the load's output velocity error or shaft position error into an electrical signal that shifts the thyatron firing angle. Conversion to an electrical signal is accomplished

by the error sensing device, but the shifting of firing angle is accomplished in the grid circuit. The desired characteristics of an ideal grid circuit are:

1. Full range (180 deg) of smooth, stepless, predictable change in output over the conducting half-cycle, and adequate sensitivity with respect to change in control voltage.
2. Reliable operation, without tube misfiring, erratic firing, or rough spots from any cause.
3. Minimum time delay in the grid circuit, consistent with required filtering of error voltage.
4. Flexibility in accepting either ac or dc error and stabilization voltages.

Three practical grid control schemes that approach the above requirements are discussed below. Other grid circuits are given in References 3, 4, and 5.

The circuit and waveforms shown in Figure 4 illustrate the simplest and most widely used arrangement for dc control of firing angle. The combination of a variable magnitude and polarity dc control voltage and a fixed lagging ac bias voltage of relatively small magnitude varies the firing angle. The capacitor in the ac bias circuit shifts the bias phase by approximately 90 deg, so that the bias now lags the anode voltage by approximately 90 deg. This small lagging ac bias increases the range of the dc grid voltage's proportional control of negative-grid characteristic thyratrons from 0 to 90 deg to nearly 0 to 180 deg. Thus adding the ac bias doubles the range of load current control.

The waveforms in Figure 4 show how the magnitude and polarity of the dc control voltage determines the firing angle. Conduction occurs only when the anode is positive with respect to the cathode and when the grid signal is more positive than the critical grid voltage. Since the grid sees the sum of the instantaneous ac bias and dc control voltages, the sum cannot exceed the critical voltage, even at the bias positive peak, when the dc control voltage is greatly negative. Thus, the tube does not conduct during any portion of the cycle and the output equals zero. But as the control voltage becomes less negative the grid exceeds the critical voltage at some firing angle and the tube conducts for the balance of the half-cycle. This condition is shown in the left waveform. The average output voltage with re-

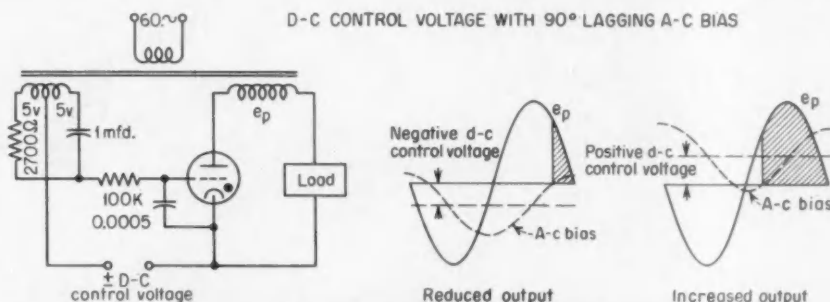


FIG. 4. The combination of dc control voltage with a 90-deg lagging ac bias increases output as the control voltage increases positively by causing the grid to fire earlier.

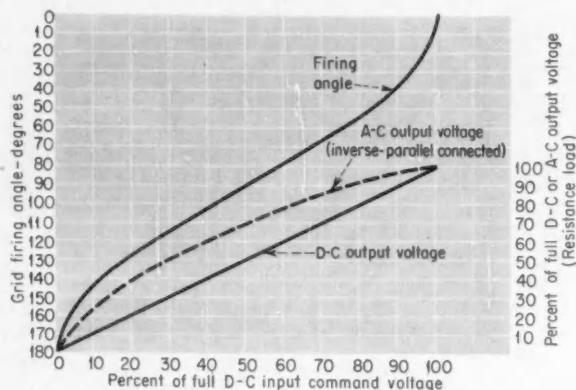


FIG. 5. These characteristics show the firing angle and dc and ac amplifier output obtained with variations in dc control voltage for the circuit of Figure 4, which uses a 90-deg lagging ac bias.

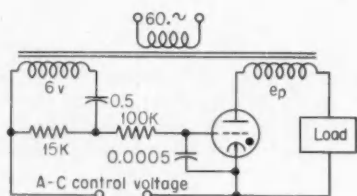


FIG. 6. A varying ac control voltage in combination with a 160-deg lagging ac bias also produces a controllable stepless output. The two signals combine vectorially to produce a shift of the firing angle.

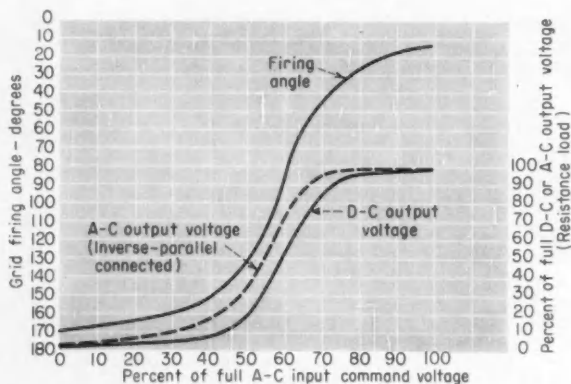
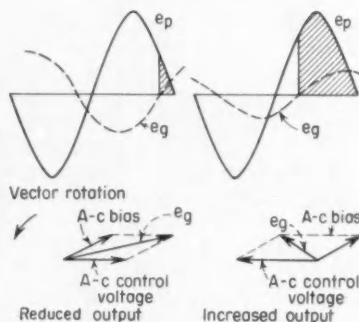


FIG. 7. The control characteristics shown here are those obtained from the circuit of Figure 6, which uses a combination of ac control voltage and 160-deg lagging ac bias.

sistance load is proportional to the area under the e_p curve (shaded) taken over the whole cycle.

The waveform at the right indicates conduction for a greater portion of the cycle: the positive control voltage permits the grid to reach critical voltage earlier in the conducting cycle. The longer the tube conducts the greater is the average load current. Thus, the magnitude and polarity of the control voltage determine the load current.

For the circuit in Figure 4 the average dc output voltage of the thyatron amplifier, with a pure resistance load and a thyatron critical grid voltage near zero, is essentially linear with respect to control voltage, as shown in Figure 5. In a servo system this control voltage would be the sum of the error and stabilization voltages. Figure 5 also shows the ac output voltage that would result if two thyatrons were connected in inverse parallel.

Figure 6 illustrates a grid control scheme which is common when the control signal is ac. The grid signal e_g consists of the vector sum of a fixed ac bias voltage, which lags the anode voltage by about 160 deg, and an ac control voltage. The R-C combination across the bias voltage winding shifts this bias by 160 deg with respect to the anode, and it remains fixed both in magnitude and phase. However, the ac control signal changes magnitude and is either in-phase or 180 deg out of phase with the anode. As seen from the waveforms in Figure 6 the vector sum e_g of these two voltages permits smooth control of the tube's firing angle by varying from nearly in-phase with the anode to nearly 180 deg out of phase. Figure 7 shows the approximate control characteristics of the circuit in Figure 6.

The magnetic reset grid circuit⁶, shown in Figure 8, fulfills most of the desired characteristics of an ideal grid control scheme, except that it has a maximum inherent delay of one cycle (the other two circuits have no inherent delay). During the first half-cycle the control voltage determines what integral of the voltage per turn absorbed by the winding P will change the magnetic state of the core away from saturation. The rectifier in winding S isolates the core from E_2 . During the succeeding half-cycle, winding P is blocked by its rectifier while E_2 furnishes voltage in winding S. The voltage is initially absorbed by S, however, and no output voltage appears at the grid until the core is restored, or reset, to the saturation level existing before the start of the first half-cycle. Thus, the amount of energy, varied by the control voltage, determines the time, or firing angle, at which the output suddenly rises and triggers conduction of the thyatron. The firing angle can be varied over 180 deg by varying R_1 , by varying the ac or dc control voltage, or by varying both. The command resistance R_1 can be a transistor or vacuum-tube preamplifier.

This circuit is independent of line-frequency variations, and is relatively insensitive to line-voltage variations since the control and grid circuit supply voltages are affected in the same proportions. Inherent

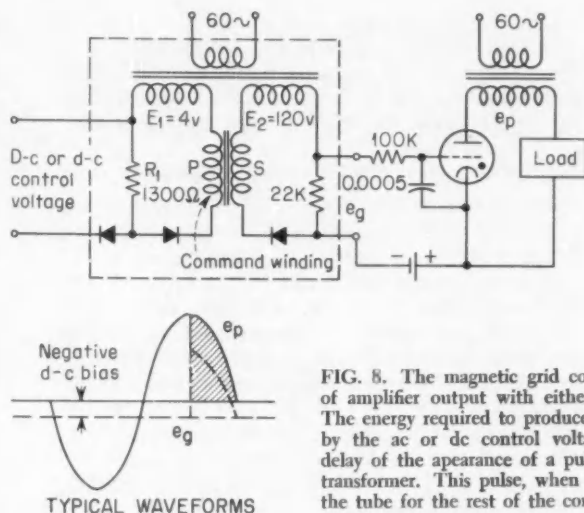


FIG. 8. The magnetic grid control circuit allows control of amplifier output with either ac or dc control signals. The energy required to produce core saturation, controlled by the ac or dc control voltage, determines the phase delay of the appearance of a pulse at the secondary of the transformer. This pulse, when it appears at the grid, fires the tube for the rest of the conduction half-cycle.

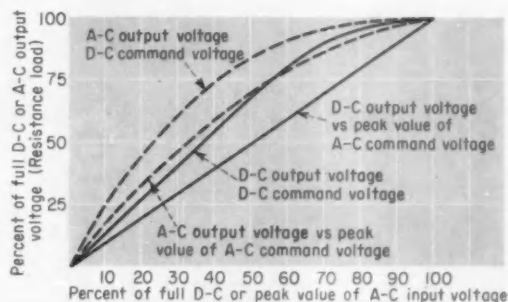


FIG. 9. The control characteristics of an amplifier using the magnetic reset grid circuit, Figure 8, are shown here.

integration of the control signal over one-half cycle filters out all usual noise, stray pick-up, and false feedback voltages in the grid circuit without slow response, the usual penalty of additional filtering.

Figure 9 shows the approximate response of a thyatron amplifier with a magnetic reset circuit of Figure 8. This figure shows the percent of thyatron full dc and ac output in terms of percent of signal voltages required for full output voltage.

Error sensing

Error sensing devices used with thyatron servos are similar to those used in other types of electrical servos. For limited-travel positioning systems the simplest error-detecting means is often two potentiometers connected across a common supply voltage. The wiper-arm position of one potentiometer determines the command signal and the wiper-arm of the other potentiometer is mechanically connected to the load. Any voltage difference between the two wiper arms constitutes the error, or control signal applied to the grid circuit. The control signal will be ac or dc, depending on whether the voltage connected across the pots is ac or dc. If the output is ac it meets the requirements as a control voltage for the grid circuits of Figures 6 and 8. If dc, it meets the requirements for Figures 4 and 8. Error systems using ac simplify preamplification problems, while those using dc avoid phase shifts of control voltage.

Synchros can be connected to give an ac error voltage of varying magnitude, and in a direction either in-phase or 180 deg out of phase with the anode voltage. Thus, synchro outputs also can control voltage in the grid circuit of Figures 6 and 8.

Velocity servos use ac drag-cup generators and dc tachometers as error sensing devices, since the output of these devices is proportional to the load shaft's velocity. Also, they provide velocity feedback stabilization for positioning servos.

Selecting the motor

In selecting a motor the designer decides how much motor and amplifier power above the minimum needed to overcome friction load can be justified to improve speed of response by overcoming load inertia more rapidly. Obviously system performance can be no better than the limitations set on it by the characteristics of the optimum motor which is available. An important figure of merit is the acceleration constant, the ratio of stalled torque to motor inertia. For fast dynamic response in driving a load the motor must have a large acceleration constant.

High-torque, low-inertia motors are commercially available in two classes:

- dc separately-excited motors
- polyphase ac induction motors

Figure 10 shows the general range of upper limit of acceleration constants pertaining to these motors. Many thyatron power-circuit arrangements for using these motors, as well as dc split field and ac repulsion motors, have been designed (Reference 2).

Figure 3 illustrated some of the basic power circuits. By far the simplest motor power circuit, and the most widely used up to 2 hp, is the half-wave circuit for a dc separately-excited servo motor, whose armature, connected in series with the ac supply line and two inverse-parallel thyratrons, provides controlled dc output and reverse rotation (Figure 3A).

Full-wave and polyphase circuits minimize delays in response to a change in command, especially for higher-power dc motors with their smaller acceleration constants. But, unlike the half-wave circuit, these circuits might short the ac supply line upon sudden reversal of command signal. To circumvent this, an interlock must be provided between the sets of tubes, or armature circuits must be isolated.

Interlock may be obtained by introducing in each grid circuit a hold-off bias voltage as long as the cur-

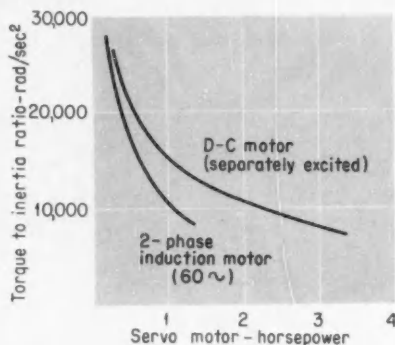


FIG. 10. For fast dynamic response a servo motor should have a large acceleration constant, the ratio of stalled torque to motor inertia. The curves shown here indicate typical maximum values of torque to inertia for dc motors (separately excited) and two-phase induction motors. The maximum available acceleration constant decreases with an increase in horse-power rating.

rent flows in any of the reverse tubes. Isolation may be accomplished with two electrically and mechanically separate armatures connected by the same load shaft. This eliminates backlash of gearing and gives wide flexibility in the degree of possible overlap of reversing voltages. If neither interlock nor isolation is used, short-circuit currents may be limited in magnitude by connecting inductance in series with the output of each group of thyratrons.

The exact output voltages of thyatron power circuits may be rigorously calculated. Ignition and extinction angles, armature back emf, tube drop, and reactance of the load, anode voltage, and the number of phases enter into the calculations.

An excellent discussion⁸ considers these factors. In practice, however, outputs may be estimated—on the basis of a resistive load, no back emf, and negligible tube drop—by such relationships as:

► dc loads

$$E_{dc} = \frac{E_a}{2.2} \left(\frac{1 + \cos X_f}{2} \right)$$

for a half-wave circuit. For full-wave circuits E_{dc} is multiplied by 2.

► ac loads

$$E_{rms} = \frac{E_a}{\sqrt{2\pi}} \sqrt{2\pi - 2X_f + \sin 2X_f}$$

for two thyratrons connected inverse parallel.

Here E_a is the rms anode supply voltage,

X_f is the firing or ignition angle in radians

Once the output values have been estimated, parameters can be modified during circuit breadboarding; this in turn enables design specifications to be met.

Thyratrons drive machine-tool duplicator

Figure 11 shows the circuit used for control of one motion of a two-motion machine-tool duplicator. An electronic error detector traces the pattern of the part to be duplicated and amplifies the error signals. Two controlled 2-hp motors drive the vertical and horizontal lead screws of the machine table slide to which the cutting tool and tracing head are attached.

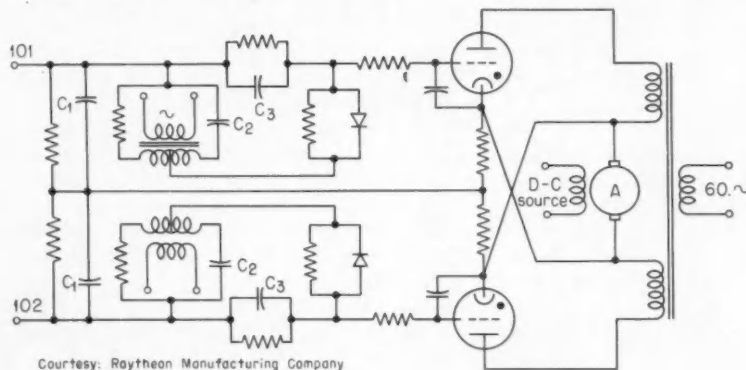
Two error signals are derived from a variable reluctance transducer, which indicates horizontal and vertical positioning errors. The error voltages are combined vectorially to give a voltage that represents the magnitude and phase of tracing-head stylus deflection. After suitable amplification and phase discrimination the resulting dc signal is introduced at terminals 101 and 102, Figure 11. An error in one direction fires the upper tube and causes corrective rotation of the motor. An error in the other direction fires the lower tube and reverses direction. One set of half-wave thyratrons drives a separately-excited dc motor for horizontal control, another for vertical control.

Two 6.4-amp thyratrons smoothly control the firing angle over a wide range by adding a dc control voltage to a shaped transient grid voltage. The latter is obtained by adding an ac 90-deg phase-shifted bias and a decaying half-wave rectified voltage appearing across capacitor C_3 . The firing angle, and hence average armature current and motor velocity, are proportional to the discriminator output. Motor armature emf in series with the discriminator output stabilizes the system.

DESIGNING AMPLIFIERS

for controlling clutches and m-g fields

Excitation of magnetic clutches and control of motor-generator fields for servo applications can also be accomplished with thyatron amplifiers, as shown by the circuits in Figures 12, 13, and 14. The thyatron's output circuit is the most distinguishing fea-



Courtesy: Raytheon Manufacturing Company

FIG. 11. The grid control circuit and load connections, shown here, drive a 2-hp motor for vertical motion of a two-motion machine tool duplicator. Motor armature back emf in series with the discriminator output stabilizes the system. A similar circuit operates the horizontal motion.

ture here; the three grid control circuits mentioned previously will also serve for these applications.

One of the simplest arrangements for controlling a highly inductive load, such as magnetic clutch or field, is the half-wave thyatron circuit in Figure 12. Here, the diode connected across the inductive load permits continuous load current and greatly increases the average dc output. During conduction the inductive load stores energy; during nonconduction (without a diode) this energy decays through the load and opposes the reversed line voltage. The induced potential forces load current to continue to flow through a portion of the inverse cycle. The duration of this flow (carryover angle) depends on the load circuit parameters $\omega L/R$. Although the flow continues for a longer time, the net result is pulsating dc load current, and the average dc current (taken over the whole cycle) becomes less as the carryover angle increases. Thus, to obtain the maximum average dc current, the carryover angle must be held to zero. The diode acts as an infinite resistance during thyatron tube conduction, but as a short-circuit during the inverse cycle. Thus, the stored energy rapidly discharges through it. The carryover angle reduces to zero, load current is continuous, and the maximum average current is obtained.

A larger ac supply voltage, used as a forcing means on the system, improves response speed in starting but increases output. The required dc output voltage may then be maintained by delaying the grid firing angle for the desired steady-state output. Resistance may be added in the back-rectifier circuit to decrease the decay time constant, but this increases heat loss.

The arrangements shown in Figure 13 and 14 speed up response to changes in signal. Figure 13 is a half-wave circuit for a dc supply to an inductive load, such as for proportional control of a magnetic clutch. Here the capacitor serves two purposes: it supports, with half-wave rectification, a continuous current in the load, and it delivers a forcing voltage to speed up variations in load current initiated by a changed grid signal.

The inverse-parallel connected tubes, Figure 14, with a shunt capacitor across the inductive load not only provide fast response, but also reverse the load current. Thus, this circuit is suitable for rapid reversal of motor-generator fields. It also results in much simpler equipment for this application than do two full-wave circuits supplying separate fields⁷.

Since the capacitor will charge up to nearly the peak of the ac line voltage each cycle (or higher if there is inductance in the supply), unless limited by delayed grid firing, this voltage is available to support load current during the nonconducting half-cycle. Upon decreasing signal or reversing signal the stored energy in the inductance transfers into the capacitor. Since the energy stored in the inductance at full load current is larger than that stored in the capacitor in any one cycle, the capacitor overcharges with reversed polarity. This overvoltage now aids the change and forces buildup of reversed current.

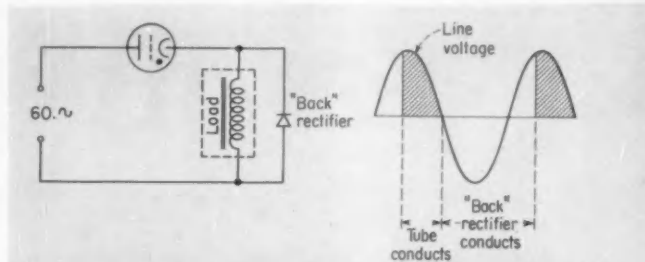


FIG. 12. A simple half-wave circuit, operated directly from the ac line, energizes a dc load, such as a magnetic clutch or motor-generator field. Here, the rectifier across the load rapidly discharges during the reverse half-cycle the energy previously stored in the inductance, assuring continuous load current, and maximum average dc output.

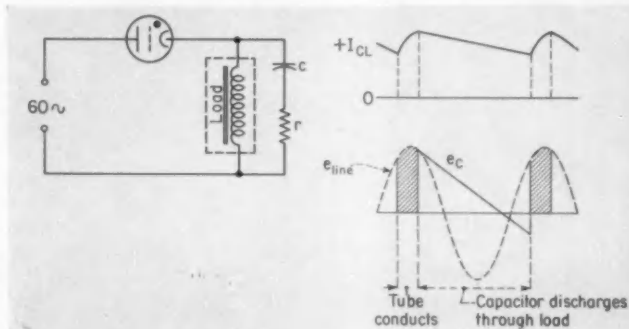


FIG. 13. This half-wave circuit employs a capacitor across the load. Besides supporting continuous load current the capacitor delivers a forcing voltage of proper polarity to the load to speed up the demanded change.

Figure 15 typifies the type of reversing response obtained from the circuit of Figure 14. Here, L equals $2h$ and R equals 30 ohms, so that the time constant equals 0.066 sec. With this load circuit the load current reaches full reverse value 0.025 sec after the reversing signal occurs.

The forcing voltage obtained on reversing signal depends on the current, load inductance, and shunt capacitance. Figure 16 shows that varying these circuit parameters varies the transient forcing voltage over a wide range. Choice of capacitor size is also influenced by the available ac line voltage, tube peak forward voltage rating, and desired dc output voltage.

Thyatron control of magnetic clutch

Figure 17 shows a circuit for energizing and deenergizing a magnetic clutch for a machine tool application. Approximate design values for a desired dc output can be calculated by step-by-step analysis, using small increments of time. A magnetic clutch rated at 90 vdc, and 0.16 amp was supplied with a half-wave circuit directly from the 240-volt 60-cps line, with a 10-mfd shunt capacitance and a peak-current limiting resistance of 50 ohms. Thus, a peak forcing voltage of $340-240\sqrt{2}$ —with an average dc

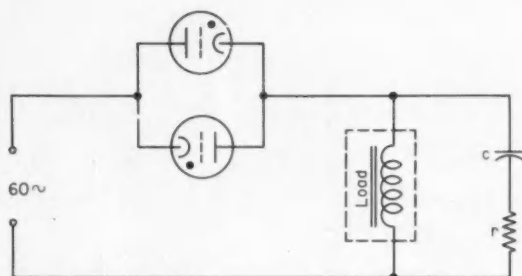


FIG. 14. Two inverse-parallel connected thyratrons permit half-wave proportional reversing control of a dc inductive load, such as reversing the field of a dc generator to reverse and control dc motor speed. Conduction of the upper tube permits current flow in one direction, while conduction of the other tube reverses polarity and thus reverses motor direction. Again the capacitor across the load builds up a forcing voltage to rapidly change motor speed and direction.

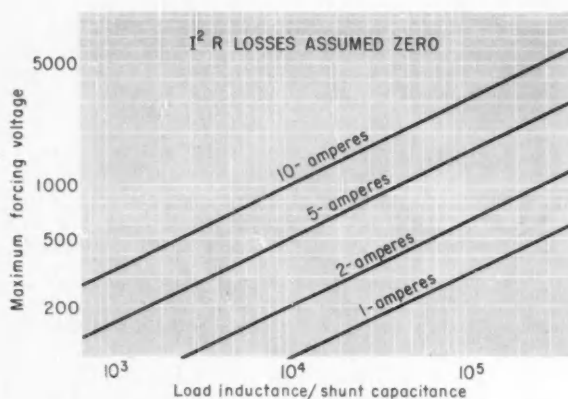


FIG. 16. The maximum forcing voltage available in an inductive load with a shunt capacitance depends on the ratio of L to C , and I . Assuming I^2R losses are zero, the family of curves shown can be obtained by equating the stored inductive energy to the capacitive energy and solving for E , at various values of current.

FIG. 17. An actual application of a thyatron amplifier for controlling a magnetic clutch is shown here. With the grid fired by closing the control switch, 90 vdc is developed across the load even though the line voltage is 240 volts rms. When the switch opens to bias the grid off and thus deenergize the clutch, the energy stored in the inductive load decreases rapidly by charging the capacitor in reverse polarity. This slight negative overshoot demagnetizes the clutch to eliminate annoying stickiness.

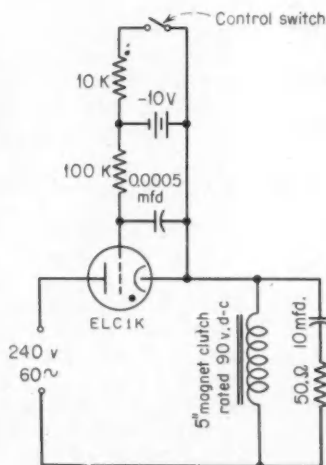
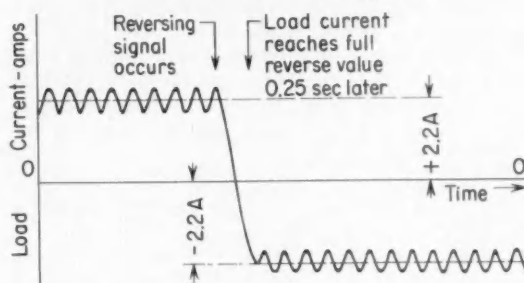


FIG. 15. The oscillogram shows that the current in a magnetic field winding having a natural time constant of 0.066 sec has been fully reversed 0.025 sec after initiation of the reverse signal. The circuit used is that of Figure 14.

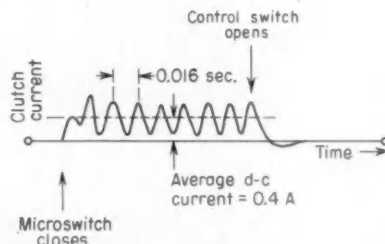


value of 90 volts set by selecting the proper size capacitor, forced rapid current buildup in the clutch.

The waveform in Figure 17 shows the resulting operation. The clutch current reaches full value in less than 0.015 sec and decays to zero in less than 0.01 sec. Note the slightly negative overshoot that occurs following current turnoff. This extremely valuable characteristic provides a simple and automatic demagnetization of residual flux in the clutch and hence eliminates stickiness.

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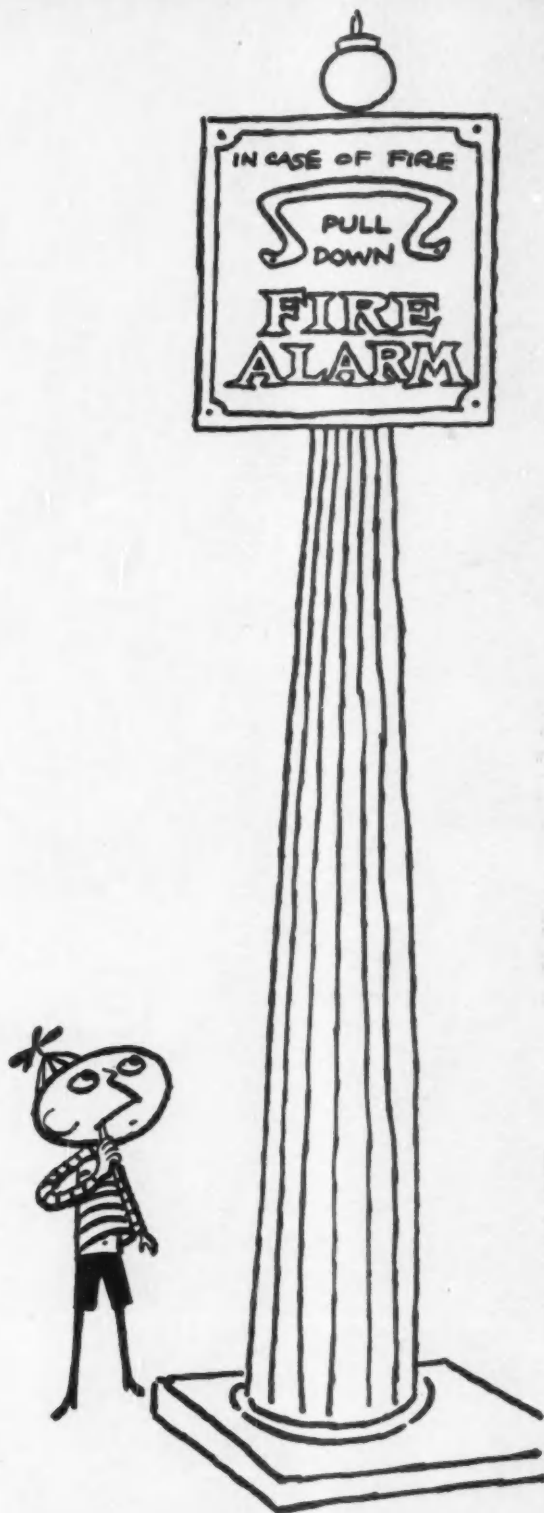
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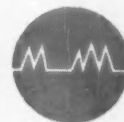
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Solving Problems With a Digital Computer

THE GIST: In article No. 7 of this series (CtE, April 1956), John Blankenbaker of Hughes Aircraft showed how a digital computer does arithmetic. This article will illustrate how such a computer, using only arithmetic, can solve problems in higher mathematics.

Necessarily mathematical, the text may appear formidable to some readers. No one, however, can leave the article without having learned how a computer working only with numbers generates values of a transcendental function or solves nonlinear equations. And, in fact, very few will come away without having absorbed something more of mathematics, for Dr. Householder writes of the technique of numerical analysis with a clarity to which only those with an intimate knowledge of a subject can lay claim.

This article is not intended to be all-embracing or to provide a compendium of formulas or computing techniques. In fact, the solution of integral equations is not discussed, and only the most elementary approach to differential equations is presented.

An outline of a computer's repertory of mathematics is followed by techniques for solving ordinary linear and nonlinear equations and systems of equations and for representing functions. References are given to advanced texts on numerical analysis.

ALSTON S. HOUSEHOLDER, Oak Ridge National Laboratory

The purpose of this article is to show how one goes about solving mathematical problems with an automatic digital computer. It supposes that somehow the mathematical representation of real or desired physical situations has been achieved and the problem is to arrive at specific numbers. The specific number required may be the value of some function corresponding to a particular value of its argument, such as the value of $\sin \theta$ when $\theta = 1.554$. Or it may be one of the numbers which satisfies a

particular equation, say $x^2 - x - 1 = 0$. In the first instance the function itself may be unknown, but defined as satisfying some equation; e.g., $x(t)$, for $t = 1.554$, where x is known only to satisfy the differential equation $\ddot{x} - x = \sin t$, with the condition that, say, x vanishes when t vanishes. These are simple, but fairly typical, cases, and generally speaking, any problem, however complex, can be analyzed into sub-problems, each of which is one of these general types.

MATHEMATICAL REPERTORY OF THE MACHINE

Both the desk calculator and the automatic digital computer are limited to the operations of addition, subtraction, multiplication, and division. The desk calculator can accept only a limited number of digits; say ten, if it has ten-digit dials. Likewise, the digital computer can accept only a limited number of digits, depending on the capacity of its registers.

In either machine, two numbers

of more than ten digits can be added, but the addition must be done in parts of 10 digits or less. A similar condition holds for multiplication. In division, however, the true quotient generally has an infinite number of digits (as when 10 is divided by 7); the machines will display only the first ten digits of the quotient on one dial and the remainder on another.

Fortunately, in the physical world, a close approximation is usually sufficient. Thus a partial quotient or pseudodivision can be obtained by pseudomultiplication. In multiplication also, a pseudoproduct is usually sufficient. In any one of the three typical problems mentioned above, no strictly finite sequence of arithmetic operations exists that would yield the exact answer, even if it were possible to carry out the arithmetic operations exactly. Nevertheless, there does exist a finite sequence of arithmetic operations (in fact, there are many such) that will give as close an approximation to the true answer as may be required. A problem of any of these types can therefore be "solved" in that a sufficiently good approximation to the true solution can be obtained as the result of a finite number of arithmetic operations carried out in an appropriate sequence. Each of these arithmetic operations must be

performed to a sufficiently good approximation by carrying out the pseudo-operations.

On a desk calculator, the operator is said to execute a routine, and if he is following a set of written instructions, these instructions constitute a program. The program may, of course, be in his head and he may even develop it as he goes along. Also written down or in his head will be certain numerical data required for defining the specific problem.

The automatic digital computer, if provided with the necessary program and data, can carry out its own routine automatically. Its data and program (expressed in such symbols as the machine understands) can be stored in its memory at the outset, and thereafter are taken from its memory and entered in its own registers (dials). The machine then presses its own operation "keys" and reads from its registers the result to be stored in its own memory, all in sequence according to the prestored program. Special "jump" commands permit the sequence to be interrupted. Such jump commands are important, for example, where a sequence of operations is performed repeatedly, each time to obtain a better approximation by using the last of successive approximations. A jump may be uncondi-

tional, or it may be carried out only when a certain criterion is satisfied. Hence the iteration can be terminated as soon as the approximation is sufficiently close.

If these things were not possible, if the human operator had to intervene at every step, then little would be gained by speeding up multiplication to a millisecond. How precisely a machine does all these things differs from machine to machine, and is discussed in other articles in this series. In short, in planning a numerical calculation the first thing is to work out a sequence of arithmetic operations that will yield a sufficiently good approximation to the number (or numbers) required in the problem. Then the special characteristics of the machine can be considered and the program arranged accordingly, the arithmetic operations being interspersed with whatever logical operations are required to get the numbers into the necessary registers, and the results back into storage. It is only the first phase, the determination of the sequence of arithmetic operations, that will be covered here in any detail. Some of the ways in which a quantity may be defined mathematically, and what numerical processes for each method will yield an approximation to this quantity, now will be considered.

ALGEBRAIC AND TRANSCENDENTAL EQUATIONS

So far in this article, only a single number was to be evaluated. There are times, of course, when many numbers, even entire tables, must be computed, but if one knows how to compute an arbitrary entry in the table then he knows how to compute them all. The organization of the computations might differ according to the number of entries required, but the basic principles remain the same. However, in solving systems of equations the values of the unknowns are interdependent in such a way that it is best to treat them all together, and when any one has been found it is often trivial to find the others.

Equations may be algebraic, as in the example given above, $x^2 - x - 1 = 0$; or they may be transcendental as in $\tan x = x$. In the latter case the unknown occurs at least once in the argument of a transcendental (nonalgebraic) function. The equation $x^2 \tan a = x + 1$, where a is given, is not transcendental, but algebraic, because $\tan a$ is defined independently of the equation. Any algebraic equation can be written in the form

$$P(x) = 0$$

where

$$P(x) \equiv a_0 x^n + a_1 x^{n-1} + \dots + a_n$$

is a polynomial. Some preliminary algebraic manipulations may be necessary (clearing of fractions, transposing, combining terms), but these are operations of elementary algebra and will be supposed understood. If $a_0 \neq 0$ the equation $P(x) = 0$ will be said to be of degree n . When $n = 1$ the equation is linear and the solution is trivial, $x = -a_1/a_0$.

A system of equations may likewise be algebraic or transcendental, and is the latter if at least one unknown appears at least once in the argument of a transcendental equation. In general, there must be as many equations as there are unknowns. If there were fewer equations than unknowns, then generally one or more of the unknowns could have values assigned to them arbitrarily and the equations solved for the remaining ones, the results depending, of course, upon this special assignment. If there are more equations than unknowns, either some of the equations are redundant, or else no solution is possible satisfying all of them. In experimental work one often obtains deliberately more equations than there are unknowns in order to reduce the statistical variance.

In such a case one does not expect that any of the equations will be satisfied exactly, but tries rather to select values that satisfy them all as nearly as possible. And even in this problem, the original equations are always replaced by another set of the right number, and this set is to be satisfied strictly, or at least up to computational errors.

Even when there are as many equations as unknowns, they may not be independent. Thus if we write

$$\begin{aligned} x^2 + y &= 1 \\ 2x^2 + 2y &= 2 \end{aligned}$$

the second equation adds no information not given in the first. Or again, they might be inconsistent. Thus the equations

$$\begin{aligned} x^2 + y &= 1 \\ 2x^2 + 2y &= 1 \end{aligned}$$

cannot both be satisfied by the same x and the same y .

An algebraic system of equations can always be written in the form

$$\begin{aligned} P(x, y, \dots) &= 0 \\ Q(x, y, \dots) &= 0 \end{aligned}$$

where P, Q, \dots are polynomials in the unknowns x, y, \dots . The degree of a term $x^a y^b \dots$ in a polynomial is obtained by adding together the

exponents of the unknown in the term: $n + m + \dots$. The largest such degree is the degree of the polynomial. If every polynomial P, Q, \dots , is linear (of the first degree), the equations form a linear system. In contrast with the case of a single equation in a single unknown, the solution of a linear system is not trivial, at least if the number of equations is at all large. Moreover, many problems reduce ultimately the solution of one or of several systems of linear equations. This case will be considered first.

It will be assumed throughout the discussion of systems of equations that the equations of the system are neither redundant nor inconsistent, and that there are as many equations as there are unknowns. Redundancy or inconsistency may be very difficult to detect, even with linear systems and only a breakdown of the normal methods of solution may reveal their presence.

LINEAR SYSTEMS

Linear systems of equations can be solved by one of the four methods: addition and subtraction, substitution, determinants, graphing. The fourth method is not numerical and will be passed over. As for the third, it will be recalled that a determinant is defined to be a certain sum of $n!$ products, each product containing n factors, and that $n + 1$ such determinants are required for all the unknowns in the equations. Consider the evaluation of the $n + 1$ determinants directly from the definition. For $n = 25$ (not an excessively large system by current standards), therefore, $25! \cdot 25 \cdot 26$ products are required. This number is approximately 10^{38} . The NORC, the fastest existing machine, will do something over 10^4 multiplications per second. Since there are other operations to be performed besides multiplication, it is perhaps fair to say that the NORC would require something over 10^{34} sec for the task. The number of seconds in one year (a full year, not a working year) is about 10^7 ; thus, if the NORC survives and has no breakdowns, it could complete the task in about 10^{27} or, roughly 3×10^{28} years. Had it started at the dawn of creation it would scarcely be warmed up to the task as of now. It is true, of course, that no one evaluates a determinant in this way, but it is also true that the operations for reducing determinants can be applied just as readily and much more effectively to reducing the system itself.

It is convenient to distinguish direct methods and methods of successive approximation. The direct meth-

ods purport to give the exact solution after a finite number of arithmetic operations. In actual calculation, since the arithmetic operations are only approximate, the result will not be exact, and without special care it can even be far off. These methods will be considered in turn.

Direct methods

Returning to high school days, one may remember systems such as the following:

$$\begin{aligned} x + 2y &= 4 \\ 2x - 3y &= 1 \end{aligned}$$

To solve this system by the method of "addition and subtraction", one multiplies the first equation by 2 and subtracts from the second, thereby eliminating x and obtaining the equation

$$-7y = -7$$

Strictly speaking, the original system has been replaced by the new system

$$\begin{aligned} x + 2y &= 4 \\ -7y &= -7 \end{aligned}$$

where the first equation is unchanged and the second has been replaced by a certain combination of the first two. Any combination, as a replacement for the second equation, would, when taken with the first equation, form a system entirely equivalent to the initial one; a particular combination is selected from which the first unknown is missing (i.e., has a null coefficient).

The solution is now trivial. By the new second equation $y = 1$; this fact along with the first equation gives

$$\begin{aligned} x + 2 \times 1 &= 4 \\ x &= 2 \end{aligned}$$

and the equations are completely solved.

One could, of course, have multiplied the first equation by $3/2$ and added, thereby eliminating y . Or one could have interchanged the two equations, thereafter multiplying the new first equation by $1/2$ and subtracting from the second, or by $2/3$ and adding.

This particular simple high-school method, in more sophisticated terminology the method of Gaussian elimination, is, in fact, one of the most effective methods for systems of any size. Consider a system of three equations, x, y , and z . One eliminates x from the first and second equations, thereby obtaining a new second equation; one must also eliminate x from the first and third, thereby obtaining a new third. The new second and the new third lack x , but both contain y and z (generally, although not necessarily). Eliminate y from these, thereby obtaining still another third equation which contains only z . From this find z ; go back to the second

equation (the one resulting from the first elimination) to find y ; then back to the original first to find x .

It is easy to see what to do with larger systems. For a system of n equations, the number of multiplications and divisions (these are the operations that take the most time) taken together is roughly $2n^3/3$.

In hand calculation (on a desk calculator) when terms are missing at the outset from some of the equations (certain coefficients are already null) an advantage obtains. In calculation with an automatic digital computer, if a general program is available it may not be worthwhile trying to modify it. The machine will then go through the motions of eliminating a variable from an equation that lacked it in the first place, and coming out, of course, with the same equation over again. Usually, however, the lost time will be negligible.

It is another story if the equation to be used for the elimination should itself lack the variable to be eliminated. Thus in the equations

$$\begin{aligned} ax + by + \dots &= e \\ cx + dy + \dots &= f \end{aligned}$$

if $a = 0$, and the machine tries to multiply coefficients in the first equation by c/a for subtracting from the second, disaster results. If these equations are themselves the result of previous eliminations, this situation cannot, generally, be anticipated. Hence one must code in a test with either a "stop" or with suitable remedial steps.

If a is small by comparison with c , though not necessarily zero, the elimination is theoretically possible but will lead to large rounding errors. In practice it is best to examine all coefficients of x , assuming this the variable next to be eliminated, pick out the largest, and transfer to first place the equation in which this coefficient appears.

The literature contains many names associated with the solution of systems of linear equations: Choleski, Doolittle, Crout, Fox, Jordan, and others. Of the various methods that have been described, a great many are but forms of the Gaussian elimination, the differences being mainly in organization of the computation, ordering of the steps, and arrangement of the intermediate recordings. It seems safe to say that of the direct methods which differ in principle, none has been shown to possess such general applicability as Gauss', although some are superior in special cases.

Methods of successive approximation

A method of this type is designed to improve a given approximation at

each step in such a way that any desired degree of approximation can be attained by taking a sufficient number of steps. Such methods are generally advantageous only when there are many equations and many of the coefficients are null. This is the case in the finite difference equations that arise as approximations to a differential equation.

Let the equations be written in the form

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + \dots &= h_1 \\ a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + \dots &= h_2 \\ a_{31}x_1 + a_{32}x_2 + a_{33}x_3 + \dots &= h_3 \end{aligned}$$

A special, but very important, case arises when the matrix of coefficients is positive definite. An explanation of this notion is found in any standard text on the theory of matrices.

The two classical methods of successive approximation are sometimes called successive displacement and simultaneous displacement. Suppose that at any stage there is the approximate solution $x_1^{(i)}, x_2^{(i)}, x_3^{(i)}, \dots$. In the method of simultaneous displacement, the equations

$$\begin{aligned} a_{11}x_1^{(i+1)} &= h_1 - a_{12}x_2^{(i)} - a_{13}x_3^{(i)} - \dots \\ a_{22}x_2^{(i+1)} &= h_2 - a_{21}x_1^{(i)} - a_{23}x_3^{(i)} - \dots \\ a_{33}x_3^{(i+1)} &= h_3 - a_{31}x_1^{(i)} - a_{32}x_2^{(i)} - \dots \end{aligned}$$

are solved for the next approximation $x_1^{(i+1)}, x_2^{(i+1)}, x_3^{(i+1)}, \dots$. In the method of successive displacement, however, these equations are solved:

$$\begin{aligned} a_{11}x_1^{(i+1)} &= h_1 - a_{12}x_2^{(i)} - a_{13}x_3^{(i)} - \dots \\ a_{22}x_2^{(i+1)} &= h_2 - a_{21}x_1^{(i+1)} - a_{23}x_3^{(i)} - \dots \\ a_{33}x_3^{(i+1)} &= h_3 - a_{31}x_1^{(i+1)} - a_{32}x_2^{(i+1)} - \dots \end{aligned}$$

In the first method, each equation is solved for the corresponding unknown in terms of the last approximate values of the others. In the second method, the newly obtained value $x_1^{(i+1)}$ is introduced before solving the second equation; this value and the value $x_2^{(i+1)}$ are introduced before solving the third equation, \dots

Since the second method uses always the most recently obtained approximation for each unknown occurring on the right, it might seem that this method is always better, although the programming might be slightly more complicated. Actually, cases have been constructed for which the first method converges and the second does not. But there are also cases (practical ones, not artificially constructed) where the second method converges and the first does not, and it is rather generally true that when-

ever both methods converge, the second converges more rapidly.

When the matrix of coefficients is positive definite, the second method always converges, but not necessarily the first. If it is true that

$$\begin{aligned} |a_{11}| &> |a_{12}| + |a_{13}| + \dots \\ |a_{22}| &> |a_{21}| + |a_{23}| + \dots \\ |a_{33}| &> |a_{31}| + |a_{32}| + \dots \end{aligned}$$

then either method converges, the second more rapidly. They continue to converge if some, but not all, the inequalities become equalities, provided there is no subsystem of, say, m equations depending upon only m of the unknowns. This proviso is scarcely a real restriction, since clearly if such a subsystem were present this system should be solved and substitution made in the remaining equations. The system thus splits into two subsystems.

Other sets of conditions, some less stringent than those given above, are sufficient to assure convergence of one procedure or the other, but they are complicated to state and also to apply. Other conditions, and also other methods of successive approximation, will be found in some of the references at the end of this article.

NONLINEAR EQUATIONS

Now to the problem of solving a single equation in a single unknown. After transposing all terms to the left and simplifying wherever possible, the equation is of the form

$$f(x) = 0$$

where either $f(x)$ is a polynomial $P(x)$ or else is transcendental. If $f(x)$ is transcendental, then there must be some method available for computing its values. This is a subject that will be discussed later in this article. But to anticipate briefly, it is perhaps evident that any method of computing on a digital computer an approximate value of $f(x)$ must amount to evaluating either a polynomial $P(x)$, or a quotient of two polynomials $P(x)/Q(x)$. Hence in order to solve a transcendental equation $f(x) = 0$ on a digital machine, one must, in effect, first seek a polynomial $P(x)$, or a quotient $P(x)/Q(x)$ that approximates $f(x)$ sufficiently well in the neighborhood of the desired root. In either event, when such a representation is at hand, one then attempts to solve the algebraic equation

$$P(x) = 0$$

For example, if the equation

$$\exp(-x) - x = 0$$

is to be solved, the exponential could be expanded in a Taylor series to obtain the equation

$$1 - 2x + \frac{x^2}{2!} - \frac{x^3}{3!} + \dots = 0$$

retaining only as many terms in the series as is necessary for the degree of accuracy that may be required. Hence only algebraic equations shall now be considered.

An algebraic equation of degree n is known to have exactly n roots. These may be real or complex, equal or coincident. If the coefficients of the equation are all real, then the complex roots occur in conjugate pairs, which is to say that if $a+ib$ is a root, then $a-ib$ is also a root; and if the first is double root the second is a double root, etc. A basic theorem is the remainder theorem, which states that if r is any number, and $P(x)$ is divided by $x - r$, then the remainder is $P(r)$, which is the result of evaluating $P(x)$ for $x = r$. Symbolically one has the identity

$$P(x) \equiv (x - r)Q(x) + P(r)$$

where $Q(x)$ is the polynomial of degree $n - 1$ that results from the division. An immediate corollary is the factor theorem, which states that if r is a root of the equation, then since $P(r) = 0$ the division will be exact. Hence if a root r is found, it can be "divided out", and all other roots of the equation will be roots of

$$Q(x) = 0$$

which is an equation of degree only $n - 1$. In practice there will be rounding errors in the computed quotient $Q(x)$, which may grow with subsequent divisions, so the techniques should be used with care.

If $P(x)$ has a double root, then this will be a simple root of the first derived equation

$$P'(x) = 0$$

where P' is the first derivative of P . If there is a triple root, this will be a double root of $P' = 0$, etc. Hence if $H(x)$ is the highest common divisor of P and P' , then all multiple roots are roots of $H(x) = 0$ and conversely. But H can be found as follows: If P is divided by P' and P_1 is the remainder,

$$P(x) = P'(x)q_1(x) + P_1$$

and the highest common divisor of P and P' is also the highest common divisor of P' and P_1 . Likewise, dividing P' by P_1 ,

$$P'(x) = P_1(x)q_2(x) + P_2$$

the highest common divisor of P_1 and P_2 . Eventually, one obtains a P_i which divides without remainder into P_{i-1} and then $P_i = H$. It may be that P_i is a constant, in which case there are no multiple roots.

In any event multiple roots, if any, can be considered disposed of and the equation $P(x) = 0$ as having only simple roots. The methods are concerned with obtaining successively

improved approximations. One method seeks the largest root in particular and another seeks them all at once. The simpler methods deal with finding just one root at a time. They presuppose an interest in finding a certain particular root, and a knowledge of a segment of the x -axis, in the case of a real root, or a region of the complex plane, within which this root and only this root lies.

Methods of successive approximation

There are many of these. Perhaps the oldest of all is the method of false positions, which applies only to real roots. Suppose r is the root in question, and suppose one knows numbers x_1 and x_2 such that $x_1 < r < x_2$, and such that for no other root r' is this true. Then $P(x_1)$ and $P(x_2)$ are opposite in sign, say $P(x_1) < 0 < P(x_2)$. On the graph of the curve

$$y = P(x)$$

let

$$y_1 = P(x_1) \quad y_2 = P(x_2)$$

and draw the line joining the two points (x_1, y_1) and (x_2, y_2) . This line crosses the x -axis somewhere between x_1 and x_2 , say at x_3 . One can calculate x_3 quite readily, and thence

$$y_3 = P(x_3)$$

It may be, of course, that $y_3 = 0$, in which case x_3 is the answer to the problem. Otherwise the point (x_3, y_3) lies either above or below the axis. If it lies above, then the required root lies between x_1 and x_3 ; if below it lies between x_3 and x_2 . In either event there is a smaller interval than before upon which the root must necessarily lie, and the process can be repeated as many times as may be necessary. The method is simple, but there seems little more to recommend it.

Horner's method, also for real roots, is almost as simple. It proceeds simply to obtain the decimal digits one after the other in the root r . Again suppose $x_1 < r < x_2$. For definiteness suppose, again that $P(x_1) < 0 < P(x_2)$. In practice x_1 and x_2 will be rational numbers, and can be thought of as integers (they are certainly integral multiples of some sufficiently small unit). Suppose, for example, $x_1 = 236$ and $x_2 = 243$. Evaluate P for the integral values of x between x_1 and x_2 and let x_3 be that integral value for which $P(x_3) \leq 0 < P(x_3 + 1)$. If $P(x_3) = 0$ the problem is, of course, solved. If not, evaluate P for $x_3 + 0.1$, $x_3 + 0.2$, $x_3 + 0.3$, . . . , and let x_4 be that number of this series for which $P(x_4) \leq 0 < P(x_4 + 0.1)$. Then increase by multiples of 0.01 and continue. Evidently as an approximation

to r , x_3 is correct to within a unit, x_4 to within a tenth, etc.

In actual practice the method does not proceed in just this way, since there is a convenient algorithm by which one can compute the coefficients in the polynomial $P_1(x')$ where

$$x = x' + x_1, \quad P_1(x') \equiv P(x' + x_1)$$

Since the roots of the equation $P(x') = 0$ are less by x_1 than the roots of $P(x) = 0$, the roots are said to have been diminished by x_1 . One would really diminish the roots first by 200 (in this example), then by 30 or 40, as the case may be, then by the appropriate number of units, tenths, . . .

The method of diminishing the roots can be illustrated by an example. To diminish by 2 the roots of

$$x^3 - x - 11 = 0,$$

write down the coefficients in sequence, followed by the amount by which the roots are to be diminished. The final scheme is

$$\begin{array}{r} 1 + 0 - 1 - 11 \quad | \quad 2 \\ + 2 + 4 + 9 \\ \hline 1 + 2 + 3 \quad | \quad -2 \\ + 2 + 8 \\ \hline 1 + 4 \quad | \quad +11 \\ + 2 \\ \hline 1 + 6 \end{array}$$

Bring down the first coefficient and multiply it by the 2 and add it to the second coefficient; multiply the sum by 2 and add it to the third coefficient. . . . Then exclude the last result and proceed as before with the others. Finally the numbers 1, 6, 11 and -2 are coefficients of the new polynomial in the equation

$$x'^3 + 6x'^2 + 11x' - 2 = 0$$

whose roots are smaller by 2 than those of the original.

For machines which operate with a binary rather than a decimal base, Horner's method is especially well suited, since one merely bisects the interval repeatedly instead of dividing it into tenths.

Newton's Method. The best known and the most general method is Newton's. If x_1 is a sufficiently close approximation to the root r , then

$$x_2 = x_1 - \frac{P(x_1)}{P'(x_1)}$$

is a better approximation. This is true whether the root is real or complex. Geometrically, in the case of real roots, this amounts to drawing the tangent to the curve at x_1 and taking for x_2 its intersection with the x -axis. Consider the expansion of $P(x)$ in Taylor series:

$$P(x) = P(x_1) + (x - x_1)P'(x_1) + \dots$$

For $x = r$, $P(r) = 0$, whence

$$0 = P(x_1) + (r - x_1)P'(x_1) + \dots$$

If one neglects the terms in the expansion which have not been written down, and solves for r , one gets just the above expression for x_2 . But this amounts to replacing the curve by its tangent. Again, in practice, the roots are diminished at each step.

There are more rapidly converging methods, but they are generally more complicated and seldom worthwhile in the long run. These will not be described here, though it is well to comment on two of them.

Bernoulli's Method. If the equation has one root whose modulus is greater than that of any other root, then Bernoulli's method provides a very simple sequence with that root as a limit. Also, if the equation has a pair of complex roots exceeding all others in modulus they can be obtained in this way. There is an extensive literature on the Bernoulli method. In principle it will yield all the roots, but for other than a few of the larger roots its utility is questionable. For one thing, the convergence is slow, although there are ways of speeding it up.

Graeffe's Method. The methods just described are self-correcting, since an error, if not too gross, will merely delay convergence somewhat. This is not true of Graeffe's method. On the other hand it converges much more rapidly, and, moreover, provides all the roots. Unfortunately, complex or multiple roots complicate the case and it becomes almost impossible to state.

NONLINEAR SYSTEMS OF EQUATIONS

Newton's method can be generalized to the case of nonlinear systems of equations

$$\begin{aligned} f(x, y) &= 0 \\ g(x, y) &= 0 \end{aligned}$$

Let a solution be $x = r$, $y = s$, and let x_1, y_1 be the coordinates of a point sufficiently close to this solution. Then, expanding in Taylor's series yields

$$\begin{aligned} f(x, y) &= f(x_1, y_1) + (x - x_1)f_1(x_1, y_1) \\ &\quad + (y - y_1)f_2(x_1, y_1) + \dots \\ g(x, y) &= g(x_1, y_1) + (x - x_1)g_1(x_1, y_1) \\ &\quad + (y - y_1)g_2(x_1, y_1) + \dots \end{aligned}$$

where the subscripts on f and g signify partial derivatives with respect to x and y . Replacing x and y by r and s gives

$$\begin{aligned} 0 &= f(x_1, y_1) + (r - x_1)f_1(x_1, y_1) \\ &\quad + (s - y_1)f_2(x_1, y_1) + \dots \\ 0 &= g(x_1, y_1) + (r - x_1)g_1(x_1, y_1) \\ &\quad + (s - y_1)g_2(x_1, y_1) + \dots \end{aligned}$$

These equations are exact only with the inclusion of the nonlinear terms, which are here signified by dots. If

one solves for r and s neglecting these terms, the result will be, in general, at best an approximation to r and s ,

but often a better approximation than the x_1 and y_1 coordinates with which one started the solution.

TECHNIQUES FOR APPROXIMATING FUNCTIONS

Since a digital machine is limited to the arithmetic operations, it can evaluate directly only polynomials with rational arguments and coefficients, and quotients of these. Hence even so simple a function as a square root can be evaluated only insofar as a rational function (a polynomial or a quotient of polynomials) that approximates it can be evaluated. An important branch of numerical analysis is concerned with methods of obtaining rational approximations.

Perhaps the best known technique is the expansion in power series:

$$f(x) = f(a) + (x-a)f'(a) + \frac{(x-a)^2 f''(a)}{2!} + \dots$$

To make use of this, there must be at least one point a at which the function and its derivatives are known. Fortunately such points can generally be found: $\exp x = 1$ along with all its derivatives when $x = 0$; $\log x = 0$ and all derivatives of $\log x$ are rational; the trigonometric functions can be evaluated geometrically for many particular angles; and so with other special functions.

Some power series converge for all values of the argument ($\exp x$, $\sin x$, $\cos x$); but in general a power series, if it converges at all, converges only within a finite circle in the complex plane with the center at a . Even when a series converges everywhere it is by no means practical to attempt to use it when $|x-a|$ is too large, and in all cases, the larger $|x-a|$ is, the slower the convergence. Often there are algebraic relations among functional values, and given one or a few special values many others can be obtained. Thus $\exp(2x) = \exp^2 x$, $\exp(3x) = \exp^3 x$, \dots ; given $\log 2$ and $\log 3$ one can obtain the logarithms of all arguments of the form $2^n \cdot 3^m$ for any n and m . Nevertheless, these provide only special values and not arbitrary values.

If the values y_0 and y_1 of a function are known and correspond to the values x_0 and x_1 of the argument, and if one wishes the value y corresponding to some value x between these, then by linear interpolation,

$$y = y_0 + \frac{(y_1 - y_0)(x - x_0)}{(x_1 - x_0)}$$

With x and y variable, this is the equation of the straight line through the points (x_0, y_0) and (x_1, y_1) . If the function increases throughout the interval, or if it decreases, the value y

so obtained is certainly closer to the true value of $f(x)$ than is either y_0 or y_1 ; this need not be the case, however, if there is a maximum or a minimum between the end-points. In some cases the same formula can be used for extrapolation, x lying outside the interval.

Formulas are available, but beyond the scope of this article, for estimating the error, whether of interpolation or of extrapolation. But if tabulated values are available other than those at x_0 and x_1 , some indication can be given by selecting the value y_2 at some third point x_2 , interpolating (or extrapolating) on y_1 and y_2 , and comparing results. For definiteness let y_{012} represent the value obtained by interpolating on y_0 and y_1 ; y_{12} that obtained by interpolating on y_1 and y_2 . A gross discrepancy between the two should lead to the suspicion that either a computational error has been made, or else that linear interpolation is inadequate.

Fortunately, the situation can be improved quite readily, supposing the computational error is ruled out. A linear interpolation on y_{01} and y_{12} , taking them as functional values corresponding to x_0 and x_2 , respectively, will yield a value of y that is in general better than either y_{01} or y_{12} . In fact, it is the value at x taken on by the parabola through the three points (x_0, y_0) , (x_1, y_1) and (x_2, y_2) . In other words, it is the result of a quadratic interpolation.

Let this value be called y_{012} . Then

$$y_{012} = y_{01} + \frac{(y_{12} - y_{01})(x - x_0)}{x_2 - x_0}$$

To determine whether this value is sufficiently close, take a fourth point (x_3, y_3) (if available), and form y_{123} on y_1 , y_2 and y_3 , just as y_{012} was formed on y_0 , y_1 and y_2 . If the discrepancy seems too great, and computational errors are ruled out, then a further improvement y_{0123} is obtained by interpolating on y_{012} and y_{123} , associating the first with x_0 and the second with x_3 . The result is that of cubic interpolation. The generalization to interpolation of higher order should be quite evident.

This method of interpolation is due to A. C. Aitken. It is especially advantageous when only a few functional values are required on any one interval. In describing the process the points were taken up in a certain order: first x_0 and x_1 , then x_2 , then x_3 .

Note that any other order would give the same final result, except possibly for slight differences due to rounding errors.

The result of interpolating in this manner on a total of $n+1$ functional values $y_0, y_1, y_2, \dots, y_n$, and hence obtaining $y_{012\dots n}$ is the same as that obtained by forming the unique polynomial $P(x)$ of degree n , which takes on the values y_0 at x_0 , y_1 at x_1 , \dots , y_n at x_n , and then evaluating this polynomial for the desired x . It is sometimes necessary, or at least advantageous, to form this polynomial explicitly. In particular, if many interpolations are to be made on the same set y_0, y_1, \dots, y_n , then it is less work in the long run to form the polynomial once for all, and evaluate it whenever necessary. In fact, in general only n multiplications are required to evaluate a polynomial of degree n , whereas the interpolation by Aitken's method requires $2^n - 1$ linear interpolations, each requiring one multiplication and possibly one division.

The polynomial can be written in the form

$$P(x) = a_0 + a_1(x-x_0) + a_2(x-x_0)(x-x_1) + a_3(x-x_0)(x-x_1)(x-x_2) + \dots$$

The coefficients, known as divided differences, can be obtained by a rather simple recursion.

For the function $f(x)$, the divided difference of order zero is just the function itself. The divided difference of order 1 is designated $f(x_0, x_1)$ since it depends upon two arguments, and it is, by definition

$$f(x_0, x_1) = \frac{f(x_1) - f(x_0)}{x_1 - x_0}$$

The divided difference of order 2 is defined in terms of those of order 1. It is

$$f(x_0, x_1, x_2) = \frac{f(x_0, x_1) - f(x_1, x_2)}{x_0 - x_2}$$

The divided difference of order 3 is

$$f(x_0, x_1, x_2, x_3) = \frac{f(x_0, x_1, x_2) - f(x_1, x_2, x_3)}{x_0 - x_3}$$

Again the order x_0, x_1, x_2, x_3 is irrelevant. Now the coefficients in the above polynomial $P(x)$ are

$$a_0 = f(x_0), \\ a_1 = f(x_0, x_1), \\ a_2 = f(x_0, x_1, x_2), \\ a_3 = f(x_0, x_1, x_2, x_3), \\ \dots$$

In these formulas, the values x_0, x_1, x_2, \dots at which the functional values are assumed given, must certainly be

distinct, but they are otherwise unrestricted. Even the requirement that they be distinct is unnecessary if derivatives are introduced. But the formulas simplify somewhat when the x 's are uniformly spaced.

The direct application of interpolation polynomials is, of course, in the computation of arbitrary functional values when only a few are given. However, one can differentiate an in-

terpolation polynomial and thus obtain an approximation to the derivative of the function at a point, and one can integrate it over an interval to approximate the desired value. However, the error in the numerical derivative can be quite large.

If a computation is to be programmed, in the course of which some function $f(x)$ will have to be evaluated many times, a few highly accurate

values of the function may be obtained in advance, perhaps from a Taylor series, but the approximating function to be programmed should be as simple as possible. An interpolation polynomial is the easiest to set up, but it is not necessarily the best representation, and, in fact, may not be as serviceable as a fraction. For more general techniques, reference must be made to the current literature.

SOLVING FUNCTIONAL EQUATIONS

By a functional equation is meant a differential equation, partial or ordinary; an integral equation; an integro-differential equation; or any other in which the unknown is not a single number or set of numbers, but a function. However, as has been seen, a digital machine can evaluate only algebraic functions. Since these are determined by a finite number of numbers, e.g. by their coefficients, the problem must be reduced in one way or another to that of solving a finite system.

Only one simple method for solving a differential equation will be mentioned here. Let this be written

$$\frac{dy}{dx} = f(x, y), \quad y(0) = y_0$$

and assume that $f(x, t)$ is a rational function. Now the equation defines the slope of a curve at every point. The equation, with initial condition, can be rewritten

$$y = y_0 + \int_0^x f[t, y(t)] dt$$

Now if h is so small that $f[x, y(x)]$ does not vary greatly between $x = 0$ and $x = h$, then approximately

$$y(h) \doteq y_0 + hf(0, y_0)$$

Hence we have an approximate value

of y for $x = h$. But then by the same rule, at $x = 2h$,

$$y(2h) = y(h) + hf[h, y(h)]$$

and the process can be continued. At each point proceed for a short distance along the tangent to the curve through that point. By taking h sufficiently small the error can be made small.

Monte Carlo Method. Functional equations of a very complicated sort arise in the study of the diffusion of elementary particles such as neutrons, and the complexity of the mathematics has led to the use of a method known as Monte Carlo, which takes advantage of high-speed computing facilities. The method, applied most frequently in principle, has its greatest practical usefulness in the field mentioned.

As an illustration, in designing a shield one is interested in knowing what fraction of neutrons entering from one side would escape out the other. To the entering neutron, assumed to have high energy at the start, the shield looks like a vast number of stationary spheres (or so we can imagine), of varying sizes, scattered about in random. According to the composition, the probability that the neutron will travel a given distance without colliding with

one of these spheres is a more or less well-known function of the distance. When it collides, the type of sphere it hits, its subsequent condition, whether it is absorbed or rebounds, again depend on more or less well-known probabilities. The Monte Carlo method is simply a method of playing the game the neutron plays, and doing it many times, counting up in the end the relative number of times the game is won by a penetration through on the opposite side. At each chance event the computing machine draws or somehow generates a random number (like throwing dice or spinning a roulette wheel) to determine the outcome of the event.

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A. S. HOUSEHOLDER

To say Dr. Householder holds an MA in philosophy (Cornell, 1927) and a PhD in mathematics (University of Chicago, 1937), and is co-author of *Mathematical Biophysics of the Central Nervous System* (Principia Press, 1945) and author of *Principles of Numerical Analysis* (McGraw-Hill, 1953) is to give a brief glimpse of a man with a firm grasp of three important fields. Dr. Householder, who has done research in mathematical biophysics (Rockefeller Scholarship to University of Chicago, 1937) and worked on lead-computing gunsights for the Navy (1944-46), joined the Oak Ridge staff in 1946. The Mathematics Panel, which he organized there, operates the Princeton-type Oracle digital computer. He was 1954-56 president of the Association for Computing Machinery.



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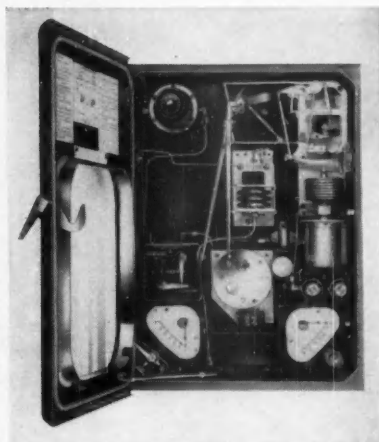
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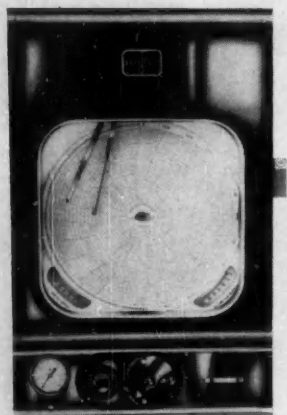
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DAVID EOLKIN, Gerber Products Co;
VICTOR HEAD, Fischer & Porter Co.

The consistency flow bridge is a measurement flow-circuit through which a pulpy slurry is pumped from a tank or main pipe at a few gallons per minute and then returned to the tank or pipe. It consists of two parallel flow paths of equal resistance, each further divided into two series flow paths of equal resistance but of unequal cross-section and length, see Figure 1. Thus, these resistances are designed so that all four viscous flow resistances are equal.

At flows up to 3 or 4 gpm flow remains laminar (no turbulence), and the measured cross-differential pressure of the bridge is zero. This holds whether the flowing fluid is water or a concentrated sucrose solution. For laminar flows, therefore, the bridge remains balanced regardless of changes in the viscosity of the liquid due to variations in solution concentration or temperature.

While the viscous resistances are balanced, the resistances related to the rheological property of a slurry known as yield stress, s , are not balanced. Insofar as the yield stress is a measure of insoluble solids concentration, or consistency, or product quality, the flow bridge differential may be used to control this quality of the product directly. Furthermore, the flow rate need not be precisely controlled;

neither does the solution temperature. Theoretically, the yield stress is directly proportional to the cross-differential pressure in the flow bridge. More exactly,

$$s = \left[\frac{3}{16 (L_b/D_b - L_a/D_a)} \right] \Delta P$$

where L_b and D_b are the length and diameter respectively of the larger tube in each leg of the bridge, and subscript a refers to the smaller tubes. For the test model bridge, the term in brackets had a value of 0.0034.

Tests were made to determine the relationship between the bridge differential and the Bostwick unit of "consistency" used by much of the food industry.

In very extensive tests of tomato pulp of many concentrations it was found that the spread of cross-differential, over a band of plus or minus 20 percent in flow through the bridge, was smaller than the spread of Bostwick readings for a given pulp concentration. It is believed that the Bostwick, which requires a specification of flow time for its reading, is inherently sensitive to viscosity and therefore cannot yield correlation with such true physical properties of slurries as yield stress (pounds per square inch), or slope viscosity (pound-seconds per square inch), but can only yield an empirical number whose value depends on the combination of these properties. Thus the Bostwick number can be decreased for an apparent increase in consistency

either by an increase in insoluble solids concentration or by the addition of such soluble matter as sugar to increase the viscosity of the liquid phase of the slurry.

The flow bridge, on the other hand, can in principle be rendered immune to soluble matter and has in practice yielded repeatable results in spite of significant temperature variations in a 30-percent sucrose liquid phase of tomato catsup. Figure 2 shows the relation of cross-differential to Bostwick (cm in 5 sec).

The flow bridge output was also compared to the value of yield stress as determined by a special laboratory shear tester. Figure 3 shows the relation between flow bridge peak differential and the laboratory test yield stress for various concentrations of tomato insoluble solids.

THEORY

The bridge resistances consist of tubes of different diameter D_a , D_b , and length L_a , L_b , such that the ratio D/D' , important in the Poiseuille equation, is the same for both. Consequently, the flow of a highly viscous Newtonian liquid will require equal pressure drop through both of the series resistances, and a differential pressure measured across the center taps between resistances of each branch will remain zero until the flow in a part of each branch becomes turbulent. If the smaller tube in each branch is designated by a , the larger

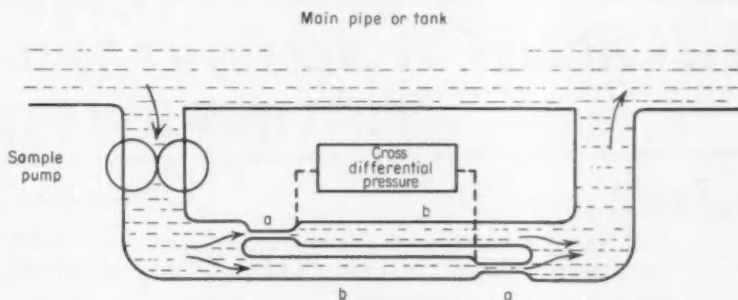
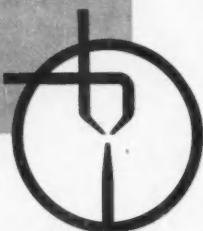


FIG. 1. Cross-differential pressure in the consistency flow-bridge is a function of slurry yield stress, independent of viscosity.

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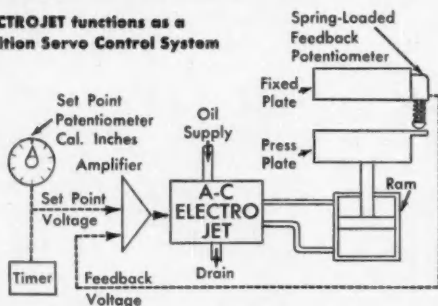


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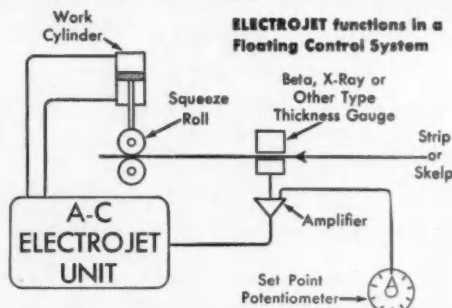
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Jet Pipe pressure.....110-150 psi std, 400 psi max.
Jet Pipe flow (examples)...1.2 mm nozzles; 100 psi, 0.6 gpm
2.5 mm nozzle; 400 psi, 5.2 gpm
Booster pressure.....2000 psi max.

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Coil resistance.....5 ohms to 20,000 ohms
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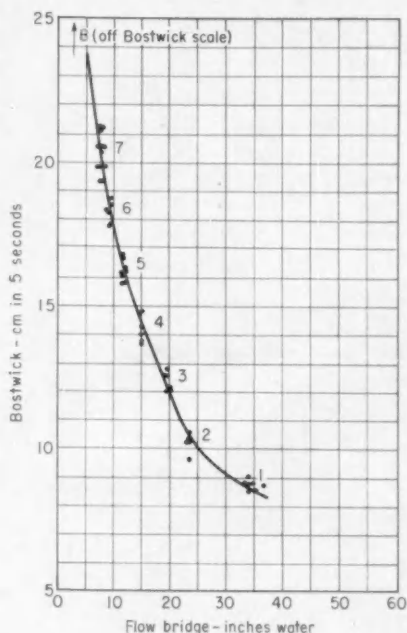


FIG. 2. Relation of flow-bridge differential to the Bostwick unit for eight concentrations of solids in tomato catsup.

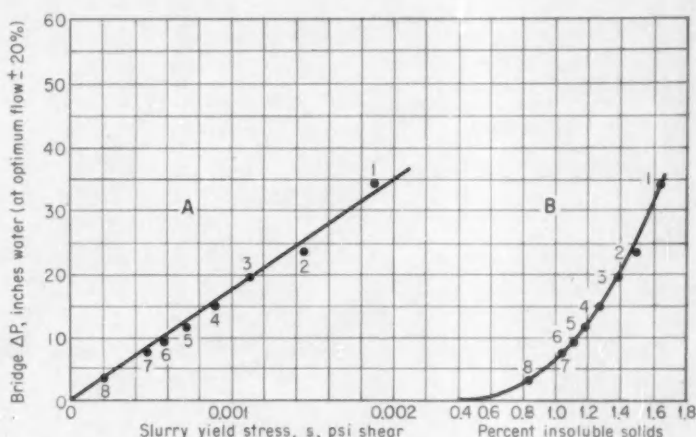


FIG. 3. A—Relation of flow-bridge differential to true yield stress. B—Percent insoluble solids in samples tested in Figures 2 and 3.

by b , it will be apparent from Figure 1 that the measured differential is equal to the friction loss in tube b minus the friction loss in tube a , or vice versa. When the flow in any tube becomes turbulent, the flow in the corresponding tube of the other branch becomes turbulent also, and the total resistance and flow in both branches remains equal. However, since turbulence will occur first in the small tubes, the friction loss in a will become greater than that in b , and the measured differential $b - a$ will be negative, see Figure 4A.

Thus, so long as flow is laminar, the cross-differential remains zero in spite of wide variations in viscosity of true or Newtonian fluids.

When the flowing material is a

"plastic", having negligible viscosity but high yield stress, the Buckingham equation for plastic flow applies:

$$P = \frac{4sL}{D}$$

and a bridge employing pairs of tubes of different sizes and balanced for viscous flow cannot also be balanced for plastic flow.

If L/D^3 is equal for a and b , then L/D must be greater for the large tube b , so that s , the yield stress of the flowing material, will be accompanied by a positive differential directly proportional to yield stress so long as there is no turbulence, Figure 4B.

Finally, in real slurries such as tomato paste, apple sauce, and paper stock, response to shear action is well

approximated by Bingham's "ideal plastics",

$$\tau = s + \mu \frac{dv}{dx}$$

where τ is local shearing stress, s is the yield stress of the slurry, dv/dx is the local velocity gradient, and μ is the slope viscosity of the slurry, or the ratio of increase in τ above the yield stress level to the gradient dv/dx .

Here, because of the action of viscosity, the cross-differential theoretically approaches precisely 4/3 of the value it would have for the nonviscous ideal as the flow increases from zero, but above a relatively small flow rate, the cross-differential is independent of the value of the viscosity until turbulence occurs, Figure 4C.

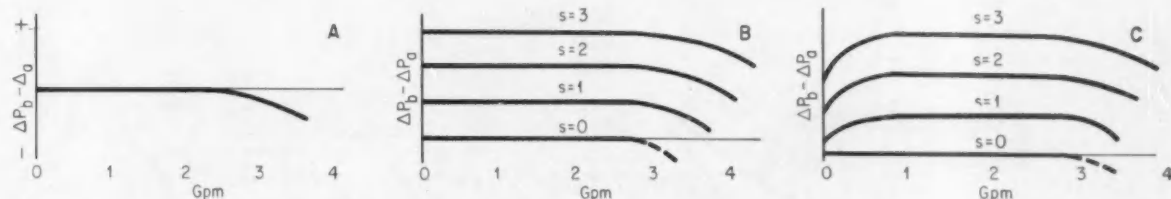
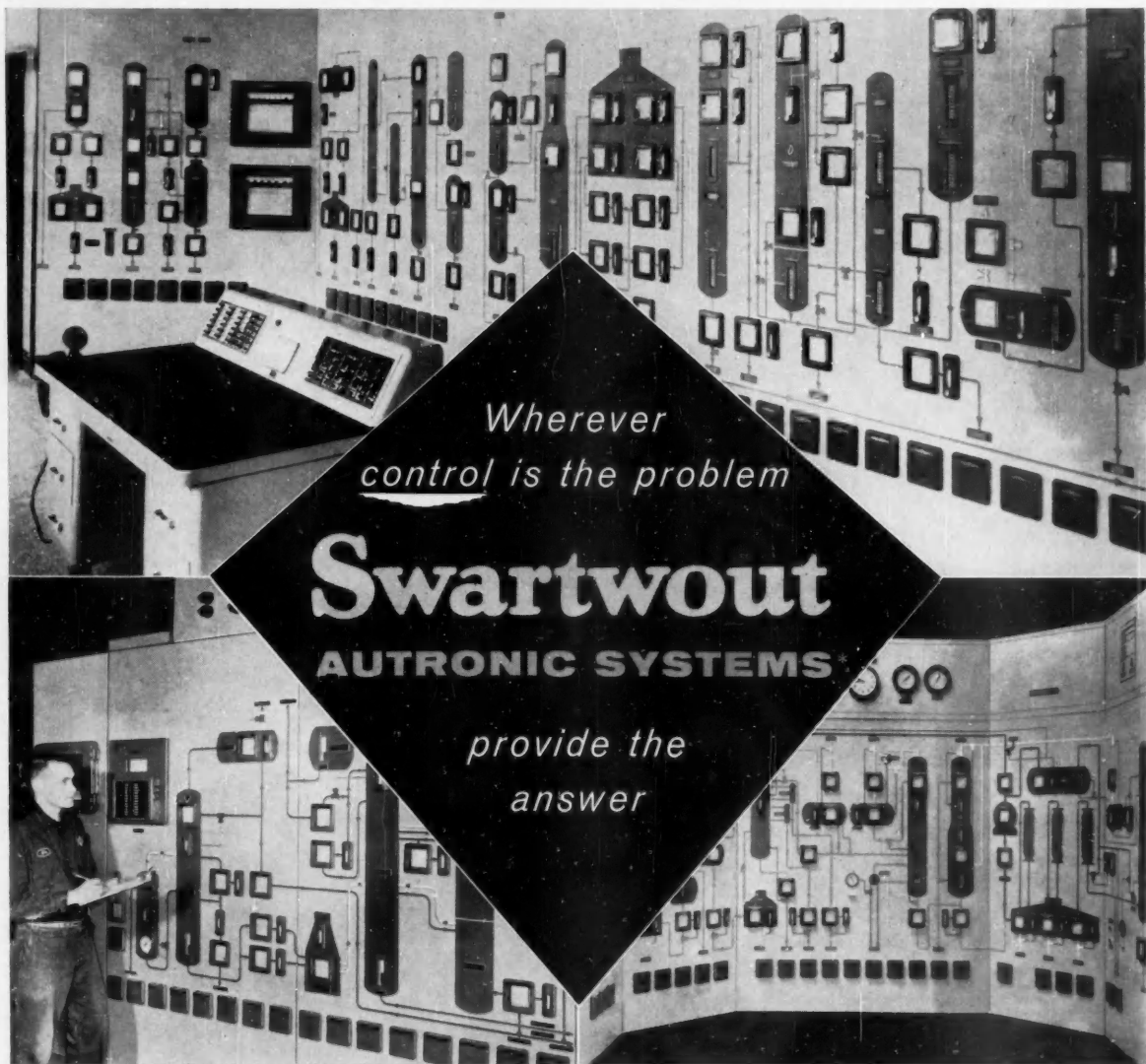


FIG. 4. A—Response of flow bridge to viscous liquids. B—Response of bridge to nonviscous plastics. C—Response to real slurries.



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Punched Tape to Shaft Position—Mechanically

ALBERT HOHMANN, Teller & Cooper, Inc.

A mechanical function generator originally designed as the essential element in equipment for checking the accuracy of fire-control-system computers contains all the features needed in a digital-to-analog programmer for controlling a machine tool. In the original dynamic tester, several of these function generators supplied various simulated director inputs to the computer to be checked, while another simultaneously produced a precalculated signal representing the theoretically correct computer output. The computer's actual output was compared to this last signal to determine overall dynamic accuracy.

In this function generator the data are stored digitally in the form of punched holes in a steel tape. The punched holes are aligned laterally across the tape with the sprocket holes by which the tape is driven, see Figure 1. A punched hole represents no change in the position of the output, but a solid section (no hole) represents a fixed incremental change in position. There are two rows of holes punched in the tape, at either side of the sprocket holes. One row represents positive increments of position; the other, negative.

Because the tape is driven through the function generator at a constant

This converter takes incremental change data stored in digital form on punched steel tape and converts them to dynamic analog shaft positions. The system is entirely mechanical. Intended originally for checking fire-control computers, it has good potential as a machine-tool controller.

speed, various functions of position vs. time can be generated by varying the spacing and relative positions of the holes punched in the tape. For example, the maximum rate of change in one direction will be generated when the row for increments in that direction has no punched holes and the other row has a hole at every position. Positive and negative increments are added algebraically in a differential, then smoothed by an integrator to produce the output. Thus, zero position change can be produced by alternating positive and negative increments. In the original application, the tape speed was 26 in.—200

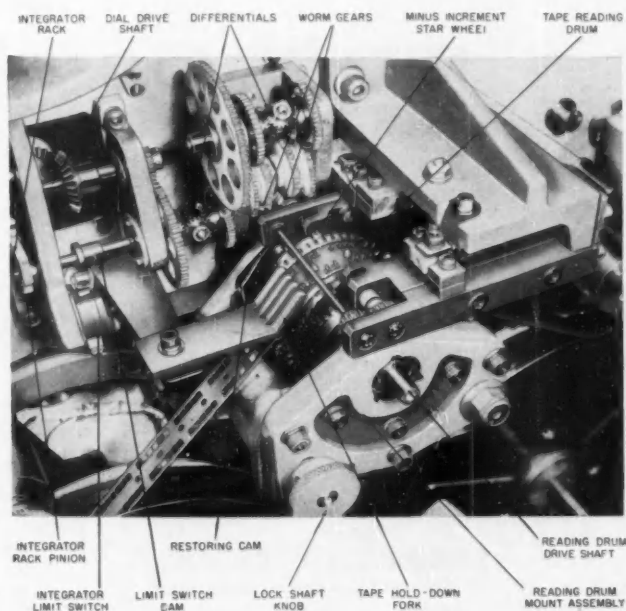


FIG. 1. All-mechanical digital-to-analog function generator.

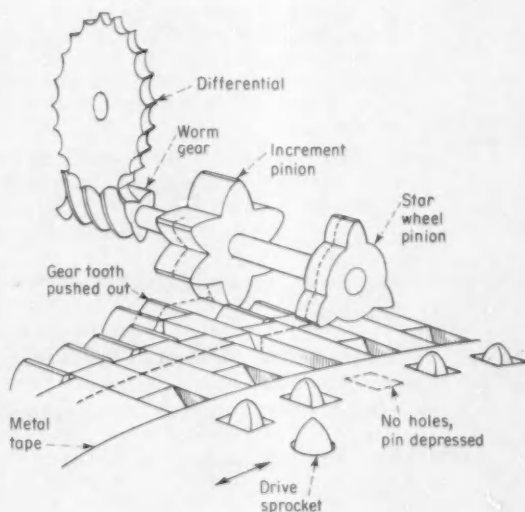
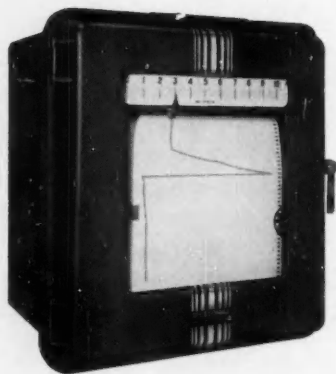


FIG. 2. Pin is depressed by tape to unlock star wheel and rotate increment pinion through 120 deg.



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MEASURING CIRCUIT—D-c potentiometer.

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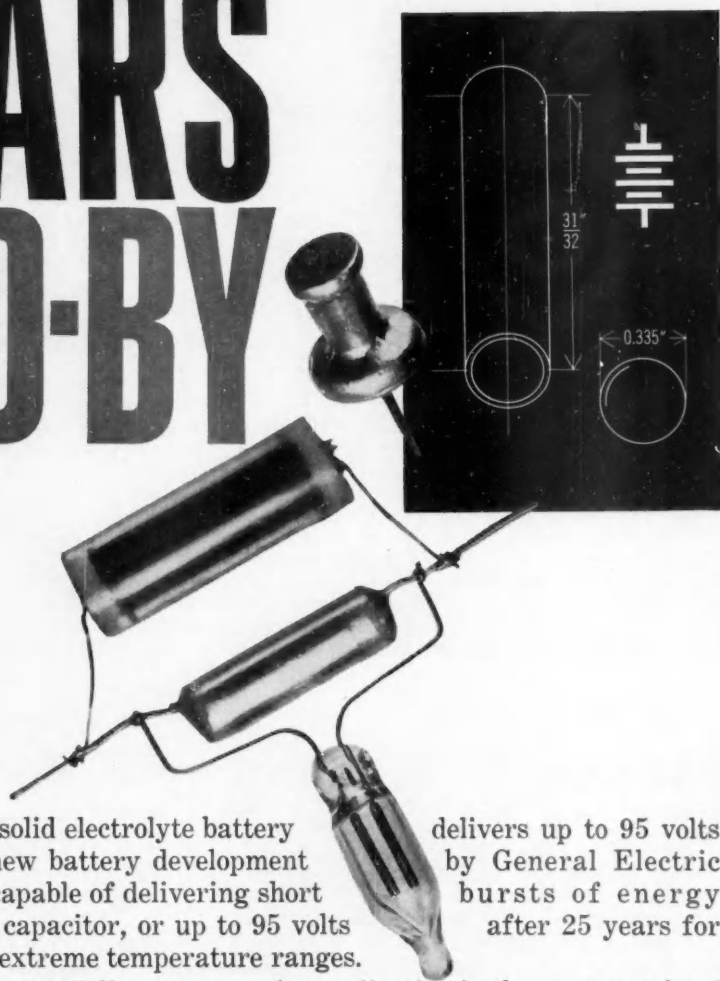
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Acoustical Filters Protect Pressure Transducers

Flush-diaphragm pressure transducers that have virtually no internal damping can be protected by low-pass acoustical filters from destruction by excitation of their natural resonant frequency. Empirical design data for such filters are included in this article

**RICHARD D. MYLIUS, and
ROBERT J. REID, Convair, San Diego**

The flush-diaphragm pressure transducer exposes its sensing diaphragm directly to the pressure medium, thereby extending practical frequency response by avoiding the lags and resonances of pressure conducting tubing. In aerodynamic applications, tubing transmission characteristics vary with ambient pressure and temperature.

More than 500 flush-diaphragm transducers were to be used for the F-102 Flight Loads Program, and flat response (within 5 percent) from 0 to 40 cps was required from sea level to 40,000-ft altitude for the majority of the measurements. The transducers had to have little or no output due to acceleration forces.

A series of tests were conducted to find the cause of failures noted in earlier programs. Exposure of the transducer diaphragm to dynamic (Continued on page 117)

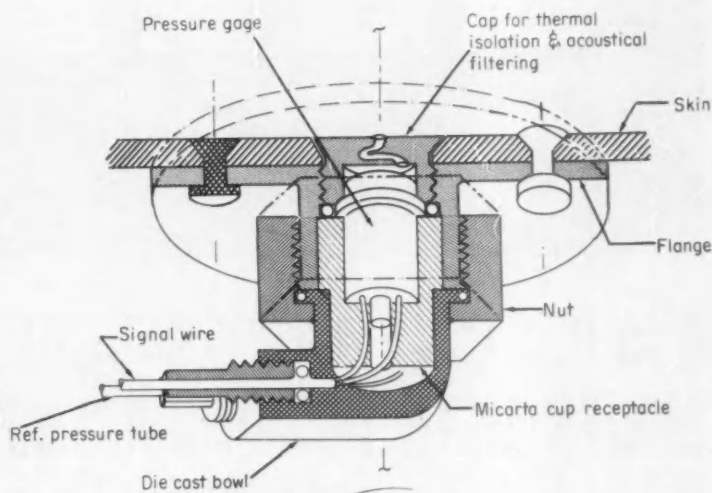


FIG. 1. Typical installation of flush-diaphragm transducer and acoustical filter.

ACOUSTICAL THEORY OF FILTER

Acoustical resistance, inductance, and capacitance are analogous to their electrical circuit counterparts and are determined, in order, by tube length, tube volume, and reservoir volume. During filter development, it became evident that the damping ratio of the smaller acoustical filters was somehow dependent upon the peak-to-peak amplitude of the applied pressure signal. Data indicating this dependence were found to be repeatable, but no available formulas had predicted that such a functional relationship could be expected to exist.

The phenomenon was found to be explainable by assuming that the smallness of the tube imposes a vari-

able mass-flow restriction that makes nonlinear the functional relationship between pressure amplitude and air particle velocity. The following empirical equation correlates with the experimental data observed during development tests. It has not been checked for tube inside diameters larger than 0.050 in.

$$b = \frac{16\mu V \sqrt{S f_n}}{R^3 P_{alt}} \left(\frac{L}{R} + 2 \right)$$

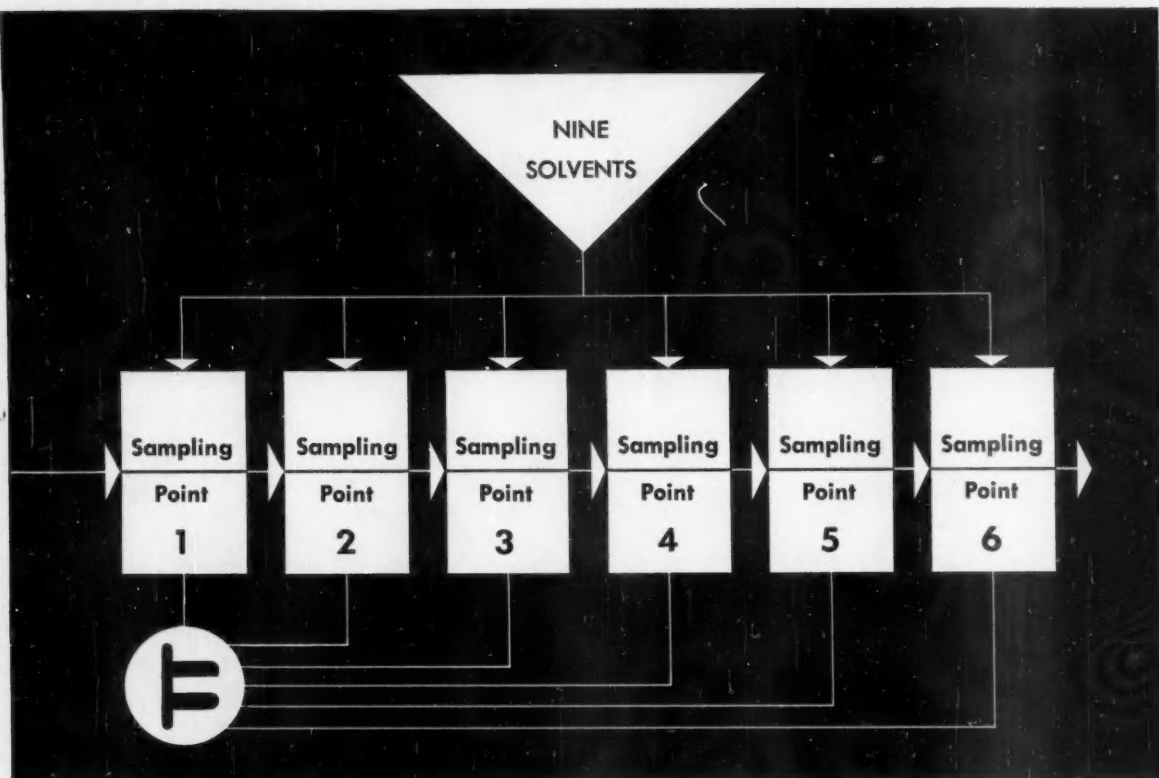
where

$$f_n = \frac{1}{2\pi \sqrt{\frac{VL}{\pi R^2 c^2}}}$$

These equations are applicable only to acoustical systems with 1 deg of freedom. Such a system is composed of a single tube of constant cross-section and a single enlarged volume partially formed by the transducer diaphragm.

SYMBOLS:

- b = damping ratio
- S = signal amplitude, lb/in.² (one-half the value of the peak-to-peak sinusoidal pressure)
- P_{alt} = ambient pressure, lb/in.²
- V = volume of cavity, in.³
- μ = absolute viscosity, lb sec/in.²
- R = inside radius of tube, in.
- f_n = natural resonant frequency of system
- L = length of tube, in.
- c = velocity of sound, in./sec



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The TRI-NON analyzer is sensitized to give an equal and linear response for each of the nine solvents. This linearity allows summation of the various combinations at each station regardless of the actual vapor concentration of any one component. Only an infrared analyzer using a selective detector can be sensitized in this manner.

One TRI-NON analyzes samples from six different points in succession along the process line at a speed of 30 seconds per point. Each point is checked every 3 minutes — often enough in this particular application to detect any dangerous change in vapor concentration. (Instrument response times up to 3.4 seconds for 98% of final value are standard.) The TRI-NON is the only infrared analyzer with sufficient speed and stability to cover so many sampling points safely.

In combustible vapor analysis, whether the system con-

tains one or a mixture of solvents, the TRI-NON provides the best zero and range stability available. It does not run into trouble when non-hydrocarbon materials are present in samples. Since it does not burn in order to analyze, deposits do not form in the detecting element and flash-back protection is unnecessary. Maintenance problems are kept to a minimum.

When you specify continuous analyzers for your process streams, P-E alone has a complete line of instruments to choose from. Or let us develop a complete analytical control system for you. Nowhere else can you get the combination of chemical engineering and instrument know-how that you'll find at P-E.

*T.M. The Perkin-Elmer Corp.

Perkin-Elmer

CORPORATION

Norwalk, Connecticut



P-E TRI-NON Analyzers are available in a wide range of models and prices to meet all types of continuous analytical problems. They are rugged and dependable, expressly designed for use in the varied environments of a processing plant or refinery. For quick and easy maintenance, instrument components can be tested right on stream — without disconnecting.

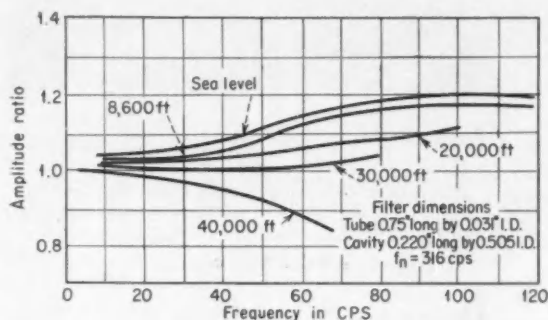


FIG. 2. Frequency response vs. altitude for acoustical filter at $\pm \frac{1}{2}$ psi input pressure.

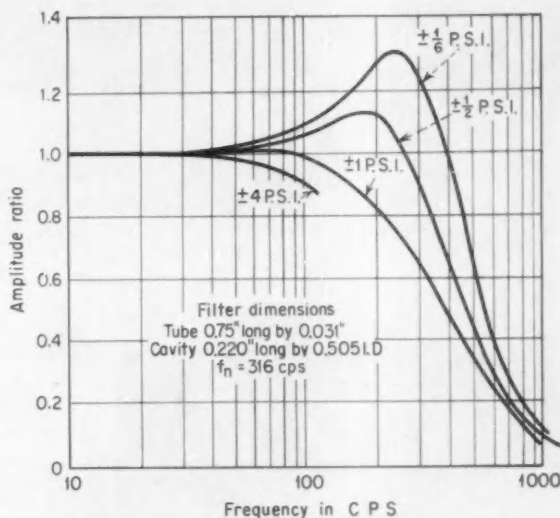


FIG. 3. Frequency response vs. amplitude at sea level ambient pressure.

temperature, changing at the rate of 6 deg per second, produced gross data errors, but there were no actual failures. It was concluded that the transducer would have to be recessed beneath the skin and thoroughly enclosed within a thermal isolation jacket.

When air blasts at speeds up to 0.7 Mach were directed against a skin panel containing a flush-mounted transducer, failures began to occur. It wasn't immediately known whether the failures had been caused by sound energy, mechanical vibration coupling or merely mishandling of the precisely constructed transducer. Although sound energy appeared to be the least likely agent of destruction, additional tests proved that it was solely responsible.

TRANSDUCER CONSTRUCTION

Such failures are explainable by examining the construction of the transducer, which consists of a four-arm, prestressed, unbonded strain-gage bridge wherein the stress levels in the individual arms are altered by minute movements of a pressure-actuated flush diaphragm. Being initially stressed and very low in mass, the unit has a high resonant frequency (5,000 cps or higher) with virtually no damping. Thus, without some means of effective isolation from, or damping of, the high frequency noise present in the airstream, the units would continue to fail upon excitation of the resonant frequency.

Damping could not be added in

the transducer without increasing to some degree the mass of the moving system and, therefore, the transducer's response to acceleration forces. Further, no type of viscous damping could be expected to remain constant over a wide range of temperatures.

Several alternative solutions to the problem were investigated, but only one of these withstood criticism from all quarters: an acoustical filter which would pass the low frequencies without distortion, but block or sufficiently attenuate the damaging high frequencies. The filter could be constructed of material having a low thermal constant and thus also serve as part of the thermal insulator. The resulting configuration is shown in Figure 1.

FILTER DEVELOPMENT

Special test apparatus was built to obtain experimental information regarding filter parameters. For testing accuracy, the dynamic pressures were applied simultaneously to a reference flush-mounted transducer and to the filter/transducer configuration undergoing test. Filter response curves were obtained by comparing the data from the two transducers.

Low frequency pressures to about 100 cps were developed by means of a stroke pump driven by electronic vibration equipment. This equipment was adapted to simulate high-altitude studies through use of a vacuum manifold system for evacuating both sides of the differential pressure transducers being tested. A 30-watt loud-speaker driver unit obtained response

curves from 100 to 2,000 cps and above.

Since flat response of the filter through 40 cps was desired for all altitudes, selection of a proper design resonant frequency was very important. It is predicted that, other things remaining fixed, the damping ratio (see damping ratio equation) will be proportional to the absolute viscosity divided by the ambient pressure. Thus, between sea level and 40,000 ft, the damping ratio of any system will increase by a factor of approximately four (Figure 2). Avoiding magnification factors larger than 2.5 at resonance would require a damping ratio of 0.2 or more at sea level. This same system would display a damping ratio of approximately 0.8 at 40,000 ft altitude. Further variations in damping ratio would occur as a function of applied signal amplitude, as in Figure 3. It is reasonable, however, to expect the larger signal amplitudes to occur at low altitudes, where the increase in damping is acceptable.

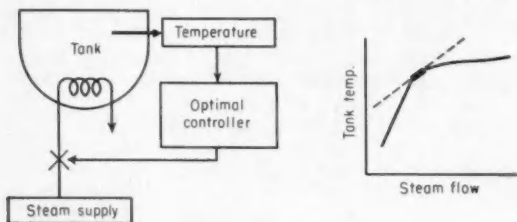
In order that fairly wide variations in damping could be permitted without noticeable effect on the system's amplitude response to 40 cps the system resonant frequency had to be at least 8 to 10 times the data frequency of interest. In other words, any damping ratio between 0.2 and 1.5 would satisfy the requirements of the Flight Loads Program if the filter natural frequency were 320 cps or higher. The curves of Figures 2 and 3 were measured for a filter with a calculated resonance of 316 cps.

NEW PRODUCTS

LISTING IN GROUPS

1-6 Designs of the Month
7-14 Research & Development
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20-24 Information Display Instruments
53-60 Accessories & Materials

25-35 Control Devices
36-39 Power Supplies
40-46 Final Control Elements
47-52 Component Parts



UNIQUE CONTROLLER optimizes operations.

Called the Quarie Optimal Controller, this device represents a new concept in system and process control. By using the slope of the process operating curve as a control parameter, the controller can maximize, minimize, or optimize an operation or process regardless of changing external conditions. It combines many of the features found in conventional process controllers with some of the logic devices of analog computers.

The photo at the left shows the controller's hinged front panel. The diagram below it illustrates a typical application. The problem given is to get the tank as hot as possible without wasting steam. This is done by plotting a curve of tank temperature vs. steam flow. As steam flow increases, tank temperature rises, but a point can be found somewhere on the knee of the curve, beyond which an increase in tank temperature cannot be economically justified. The slope at this point represents the desired control slope. The curve shown here is based on a single steam supply temperature. If then a family of curves were drawn, each for a different steam temperature, the most economical tank temperature would always be found at the point where the slope of the curve becomes parallel to the desired control slope. By maintaining a slope rather than a point, the controller assures the most economical operation.

Maximum and minimum problems are similarly solved by selecting points of zero slope. Such problems might include maximizing range or minimizing fuel cost of a locomotive by control of throttle setting. Many other more interesting applications are covered in the available literature.—Quarie Controllers, Canton, Mass.

Circle No. 1 on reply card



VERNIER POTENTIOMETER lacks parallax.

Simplicity of operation and ease of mounting are two outstanding features of this new vernier potentiometer.

A single knob operates either of two resistance decades or the interpolating potentiometer with a simple positive drive. Resistance decades are changed by pulling out or pushing in on the knob, and numbers are read out as the knob is rotated. Manufacturer claims that this design eliminates parallax and confusion. Three turns cover the full range.

The complete unit mounts similar to a square cased panel meter and matches the 3-in. meter in size and shape, except for depth behind the panel. It has an input resistance of 10,000 ohms, and a linearity within 0.01 percent.—Research Instrument Co., Portland, Ore.

Circle No. 2 on reply card

MOISTURE MONITOR aids research.

Portable and dependable, this instrument accurately measures minute quantities of moisture in gaseous mixtures. Called the Type 26-301 Moisture Monitor, it is expected to solve many problems encountered in research, quality control, and process efficiency. For example, it will measure water content down to one ppm, and permit precise meter readings over the full-scale range of 0 to 1,000 ppm.

In operation, an electrolysis cell in the instrument continuously absorbs and electrolyzes all water present in a sample stream. A dc voltage is applied to the cell and the electrolysis current is used as an indication of water content. Unit operates on 105-125 vac.—Consolidated Electrodynamics Corp., Pasadena, Calif.

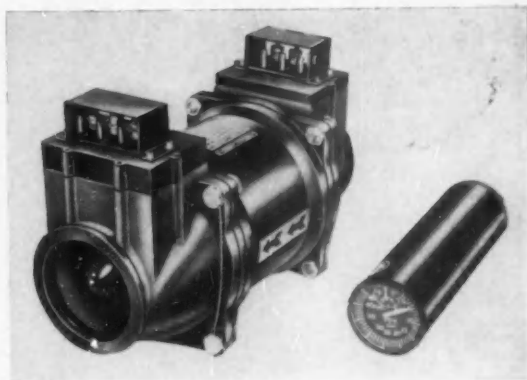
Circle No. 3 on reply card



COMPACT SYSTEM indicates mass flow.

Designed for use in jet aircraft, this system provides true mass flow indications without the use of density correcting devices. It consists of only two units: a transmitter mounted on the fuel line, and a panel indicator. Operating on the "torque" principle, the system obtains flow rate signals by means of two turbine wheels in the transmitter. A constant speed impeller imparts a momentum to the passing fuel proportional to mass flow rate. This momentum causes a deflection, through a sensing wheel, in a low torque potentiometer. Thus the output is a signal directly proportional to mass flow rate. This signal is then modulated to produce an indication, in pounds per hour, at the integrally lighted panel indicator.—Avien, Inc., Woodside, N. Y.

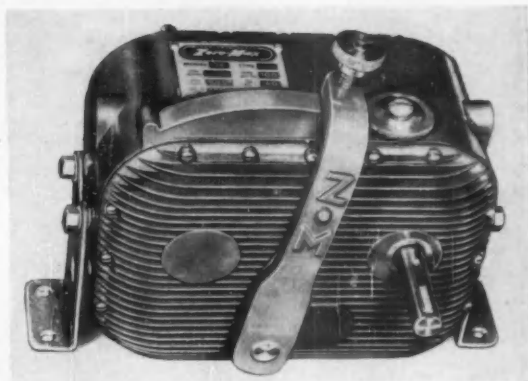
Circle No. 4 on reply card



LEVER CONTROL improves speed reducer.

Faster speed changes and simpler remote control set-ups are two of the advantages claimed for the new lever control now available on this infinitely variable speed reducer. The new lever control permits the output speed setting to be changed instantly. This can be done while the unit is operating or stopped and, as with earlier models, the output shaft can be stopped by means of the control without stopping the power source. Remote controls are easily set up because the forces required to move the control lever are small even when the unit is under load. The lever has a 40-deg movement and the large quadrant is easily calibrated for any particular application.—Revco, Inc., Minneapolis, Minn.

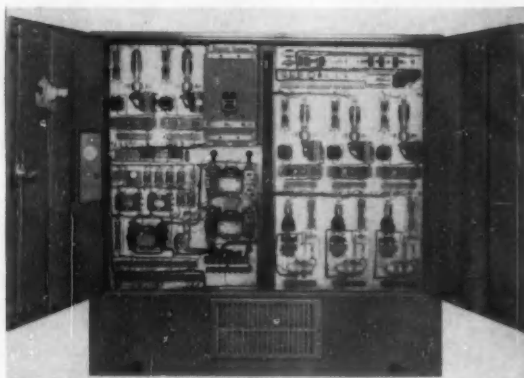
Circle No. 5 on reply card



NEW SPEED DRIVES have fast response.

Shown is the front view of one of a series of electronic variable speed drives now available in capacities of from 30 to 150 horsepower. Each unit consists of an operator's control station, an electronic control cabinet, and a dc motor. Dynamic braking, reversing, forward-reverse jog operation, tachometer feedback, acceleration, and armature current-limiting are included as standard features of the drive. With the exception of the dc motor, all components are static and have no inertial properties to slow down response. Ignitrons, thyristors, and magnetic amplifiers provide full-field starting, smooth acceleration, and infinitely variable speed over a wide range. Regulation is said to be within 1½ percent or better.—Raytheon Mfg. Co., Waltham, Mass.

Circle No. 6 on reply card





DIAL THERMOMETERS

in 3 types to suit any requirements



Full 4 1/2" dial face. Stem can be placed at any angle and case can be rotated to any readable position.

1 Rigid Stem Dial Thermometer tapered bulb, interchangeable with standard industrial thermometer separable socket. (As illustrated above.)

2 Wall Mounted Dial Thermometer with flexible connecting armor. Case adjustable to easy reading position.

3 Flush Mounted Dial Thermometer for panel mounting with flexible connecting armor.

All three types have a full 4 1/2" dial face.

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NEW PRODUCTS

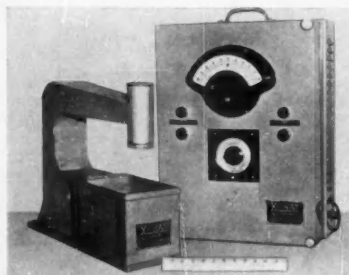
RESEARCH, TEST & DEVELOPMENT



STORAGE SCOPE

Tagged the Model 103 Memo-Scope, this instrument combines the quality of information persistence with all the features of a quality lab oscilloscope. The unique storage tube permits the operator to capture and retain any number of traces. These can be held indefinitely at a constant intensity until intentionally erased. Traces are visible in a brightly-lighted room and may be easily photographed. The scope is available in two models: portable as shown here, and rack mounted.—Hughes Aircraft Co., Los Angeles, Calif.

Circle No. 7 on reply card



PORTABLE X-RAYER

This portable electronic noncontact gage was designed specifically for measuring thickness of material in process. Accuracy is said to be within 1 percent of a predetermined standard. In operation, energy from an X-ray beam is passed through the material being measured. Variations from a preset weight, density, or thickness

can be controlled by means of auxiliary automatic control equipment.—Industrial Gauges, West Englewood, N. J.

Circle No. 8 on reply card



CONSTANT TEMPERATURE

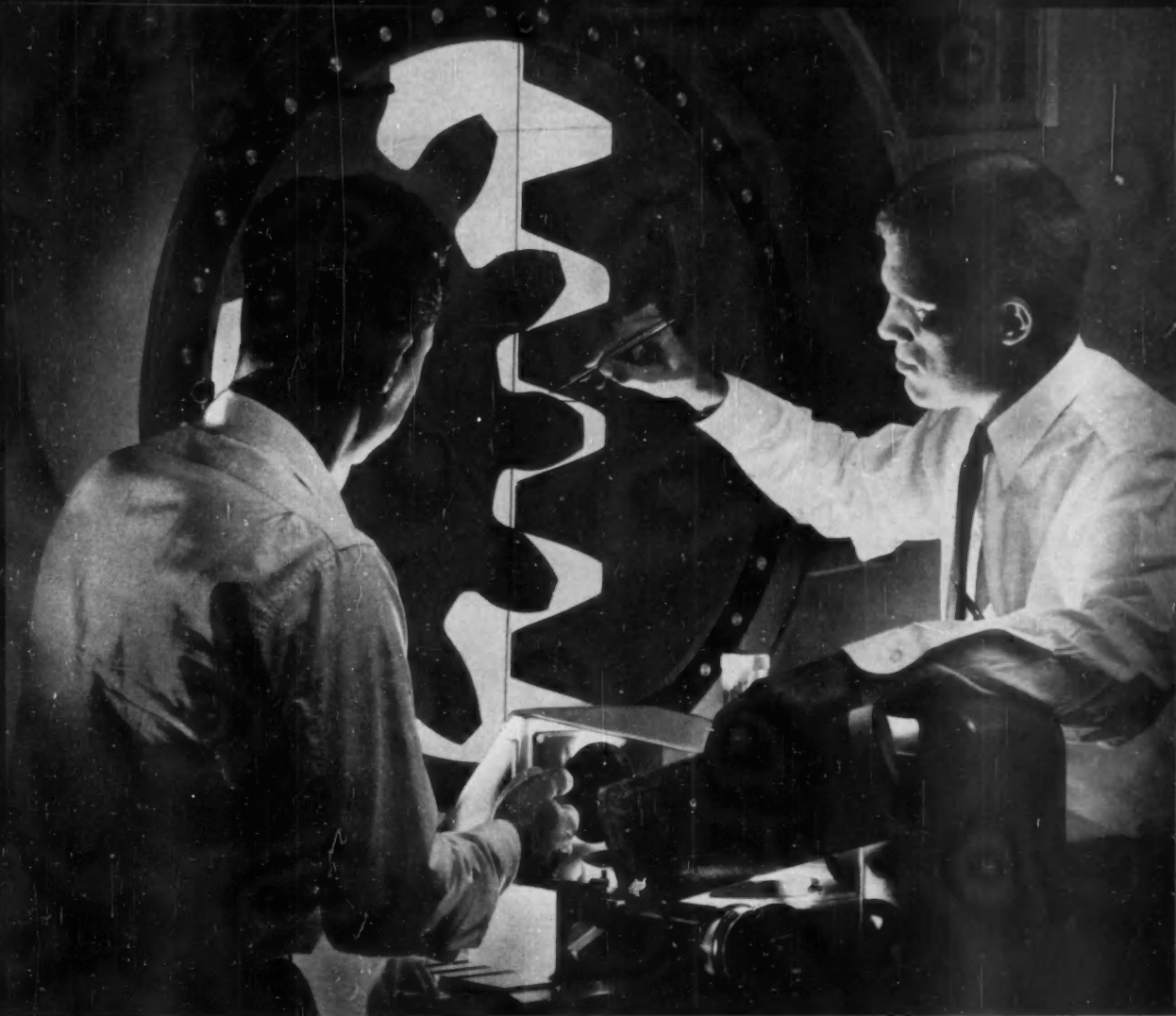
The constant-temperature bath above, one of two new models, is mechanically refrigerated and has a control accuracy within 0.002 deg C. Temperature range extends from 0 to 150 deg C. Other features: a built-in refrigeration unit, built-in pump stirrer, resistance thermometer, precision bridge circuit, and temperature controller. A second model, with the same accuracy, covers the range of 20 to 150 deg C. This model features a 16-in. diam pyrex jar, a random stirrer, and a power proportioning temperature controller.—Apex Scientific Co., Orinda, Calif.

Circle No. 9 on reply card



SINE AND SQUARE WAVES

This compact, moderately priced function generator covers a frequency range of 0.1 to 120 cps. It produces both sine and square waves. Maximum output for the sine wave is 24 volts peak to peak, for the square wave 16 volts peak-to-peak. Because of its low frequency range, the unit should prove suitable for servo work, transient studies, and laboratory appli-



Gear teeth get in line when he takes a hand

R. L. Thoen, right, explains faulty tooth conformation on a minute gear which has been enlarged 100 times in this king-sized projector. Gear specialist on the engineering staff of the Mechanical Division of General Mills and author of numerous technical papers, Thoen makes gear trains perform with uncanny accuracy. He helps design and build the special machines which make such accuracy routine work at the highly specialized plant.

Next to its men, General Mills is most proud of its machines. For it is this combination that mass produces gear trains with nearly imperceptible backlash, total cumulative error of 0.0002 inch, angular tolerances within 40 seconds of arc, positioning accuracy within 0.01 percent.

This typical General Mills precision production is possible only because men like Thoen have improved standard tools, created special machines, devised ingenious attachments. Some equipment is operated under strict tempera-

ture-humidity control. All is backed with the finest inspection devices. You can use these machines and the men that created and operate them to produce your precision products. You'll profit. A simple request brings more facts.



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Learn how our men and machines eliminate irksome production problems. Write Dept. CE1, Mechanical Division of General Mills, 1620 Central Ave. N.E., Minneapolis 13, Minn.



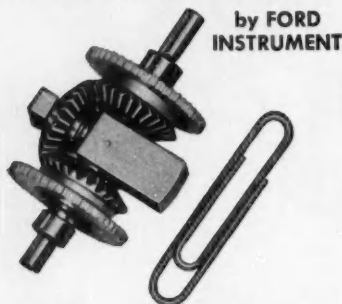
General Mills Pioneers Scientific Frontiers One of General Mills' numerous research projects involves the behavior of metals in space flight. Here a scientist determines the "sputtering" or disintegration rate of molybdenum at 200 miles above the earth. The metal is under fire from atoms moving at 25,000 m.p.h.

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NOTE! Prices of 1/8" units have been drastically reduced.

GUARANTEED SHIPMENT WITHIN:

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*Note: 3/16" units are not stocked with set shaft lengths.

Ford Instrument produces single spider gear differentials to highest military and commercial standards, for extreme accuracy in addition and subtraction, and in servo loop applications. Seven ways superior. Call or wire W. Mohr, Component Sales Division (STILLWELL 4-9000) for prices, or check and mail coupon below, stating quantity. Data bulletin with performance curves and characteristics will be sent with the prices.



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Please send me prices on the following:

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I want _____ (number) units:

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Company _____

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City _____ State _____

NEW PRODUCTS

cations. A separate attenuator and monitor can be supplied to provide constant-amplitude signals in the microvolt and millivolt region.—Engineering Specialty Co., Salt Lake City, Utah.

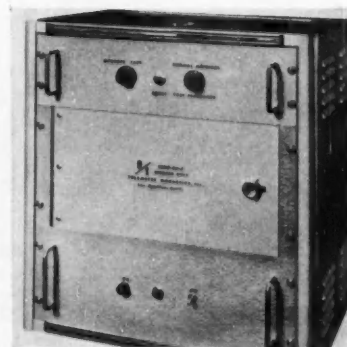
Circle No. 10 on reply card



INTERVAL TIMER

The 11.110-sec maximum time interval of this decade interval timer is calibrated in thousandths of a second. A variety of switching operations can be controlled by the timer by four separate switching circuits from the "start" relay and four more from the "stop" relay. Any desired time interval within the range may be set up within a few seconds by simply positioning the four large knobs on the front of the panel. Basically, the unit consists of an electric circuit in which a resistance-capacitance network controls the time interval.—Hunter Mfg. Co., Iowa City, Iowa.

Circle No. 11 on reply card



BUFFER STORAGE

Said to be ideal for use in data processing and computing systems, a new

coincident-current magnetic core storage unit features a capacity of 1,092 characters, each of which may be seven binary digits in length. The seven bits of each character are loaded and unloaded from the memory in parallel. Characters are introduced sequentially and are immediately available at the output in the same sequence. Completely transistorized, the unit has a self-contained power supply and fits a standard relay rack approximately 21 in. high. Minimum time for a loading or unloading operation is 14 microsec per character with 6 microsec required to switch from a loading to an unloading operation.—Telemeter Magnetics, Inc., Los Angeles, Calif.

Circle No. 12 on reply card



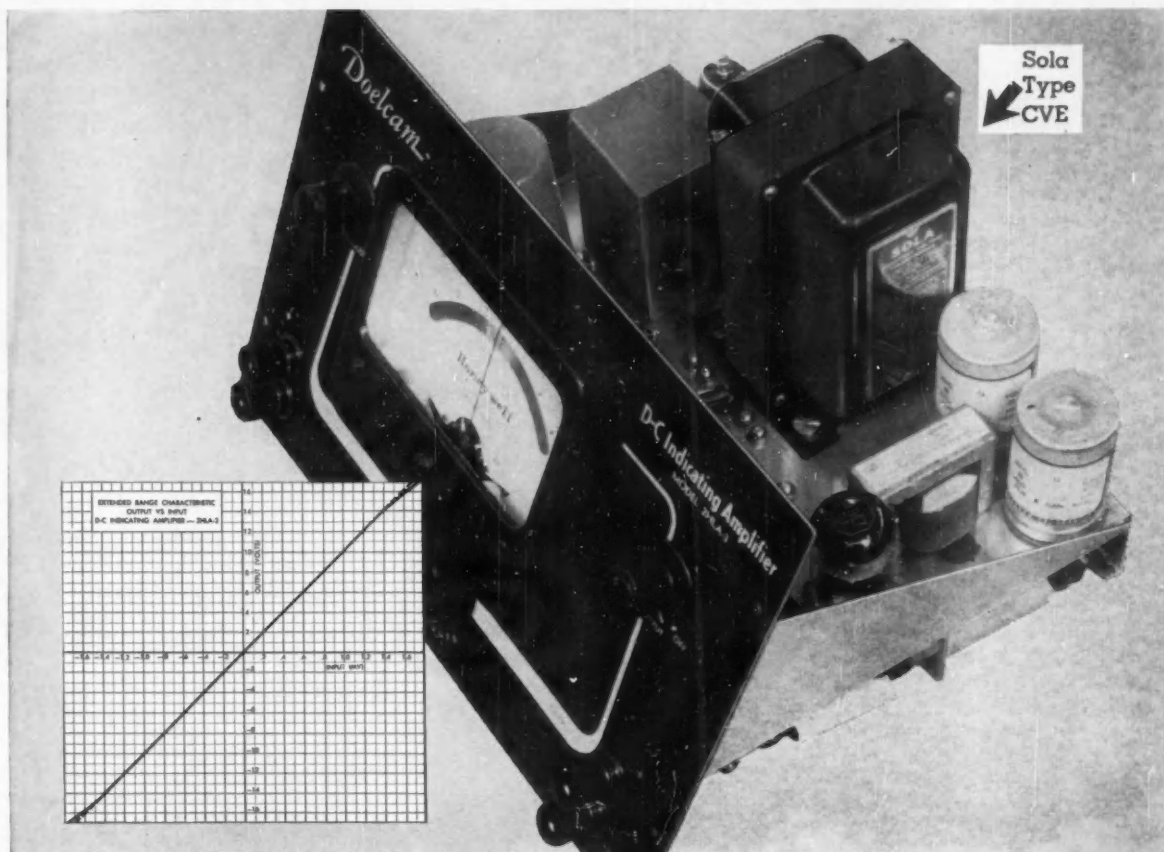
MISSILE CHECK-OUT

The system pictured here is designed for obtaining absolute dc and ac voltages, frequency values, and go/no-go checks on various missile components. Extremely flexible, the system requires only a change in programming to accommodate changing test requirements. It consists of three basic groups: program, control, and measurement. Program units include an input scanner, a programmer, a computer, and a punched card memory and printer. The control unit consists of visual indicators and the necessary circuitry. Measurement units are an ac-dc digital voltmeter and a time interval meter. Maker claims that this system can be easily expanded to include similar measurements on ac and dc ratios and resistances, using standard modular units.—Electro Instruments, Inc., San Diego, Calif.

Circle No. 13 on reply card

INFO DELAY GENERATOR

Designed for analog computers, this Model 3770 Information Delay Gen-



Above is the 2HLA-3 Indicating Amplifier, a product of the Doelcam Division of Minneapolis-Honeywell. Housing is removed to show chassis-mounted Sola

Type CVE Regulated Power Supply Transformer. Inset is an extended-range characteristic showing linear amplifier output.

Sola-Regulated DC Amplifier Provides Reliable Measurement of 2×10^{-15} W Signals

The Doelcam 2HLA-3 DC Indicating Amplifier has introduced a standard of performance heretofore unattainable in the field of amplification and measurement of low level dc signals. This precision instrument measures signals as small as 2×10^{-15} watt. High gain, excellent linearity, and negligible drift of the 2HLA-3 are unaffected by variations in line voltage or tube characteristics.

Contributing to this reliable and stable performance of the Doelcam amplifier is its chassis-mounted Sola Type CVE Regulated Power Supply Transformer. The Sola CVE static-magnetic stabilizer provides a single, compact source of plate and filament supply voltages regulated within $\pm 3\%$, with input voltage variations of 100-130 volts. All windings are on the same core, pro-

viding a moderately-priced unit to replace both voltage-regulating circuit, or component, as well as conventional power transformer.

These Sola transformers are available in three standard models ($\pm 3\%$ regulation); or in special designs with regulation of one winding as close as $\pm 1\%$. They have no moving parts or tubes, and are completely automatic, instantaneous, and continuous in operation. In addition, they provide self-protection against short circuit, and require no maintenance.

Your area representative will be happy to provide you with information on the specific benefits of a Sola Type CVE Regulated Power Supply Transformer as a component in your product.

SOLA

Constant Voltage
TRANSFORMERS

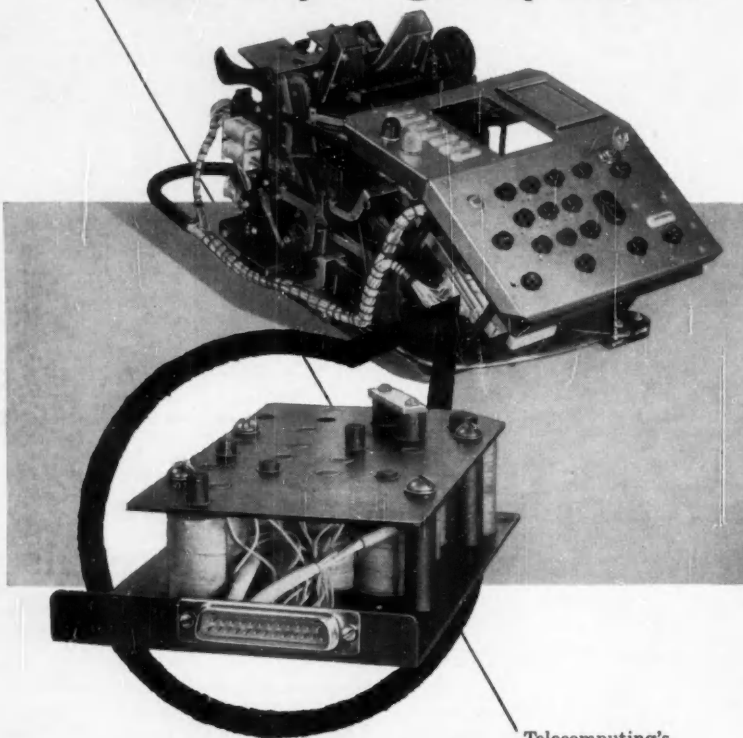


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miniature solenoids solve control problem for Telecomputing Corporation



Telecomputing's Point O' Sale Recorder handles thousands of daily retail sales automatically.

The recording operation starts at the input keyboard. Each of the eighteen keys actuates a miniature solenoid. Telecomputing engineers required solenoids which would do a big job in small space, which would be reliable, fast, accurate. They solved this problem with WesCo miniature solenoids.

Together, WesCo and Telecomputing engineers packaged the eighteen small solenoids, wiring and connectors into a module. This package fits under the keyboard of the Point O' Sale Recorder.

If you too, need a solenoid for maximum work in small space, WesCo has many miniature, sub-miniature, single or multiple solenoid designs for you.

THE TRADEMARK
ON MILLIONS
OF SOLENOIDS
SINCE 1927



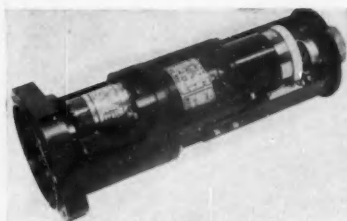
**WEST COAST
ELECTRICAL MFG. CORP.**

NEW PRODUCTS

erator accepts input data in the form of a voltage varying with time and within the limits of plus or minus 100 volts. The unit delivers the same data at the output terminals after a time delay of anywhere from 0.02 to 2.0 sec depending on the range used. The delay interval, indicated to within 1 percent on a large meter, is linearly adjustable by means of a single knob. Two or more units may be cascaded for distortionless reproduction of even higher frequencies, or to achieve proportionately greater time delays.—Donner Scientific Co., Concord, Calif.

Circle No. 14 on reply card

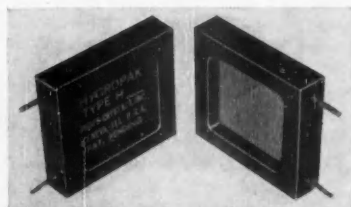
MEASUREMENT & DATA TRANSMISSION



NEW DATA REPEATERS

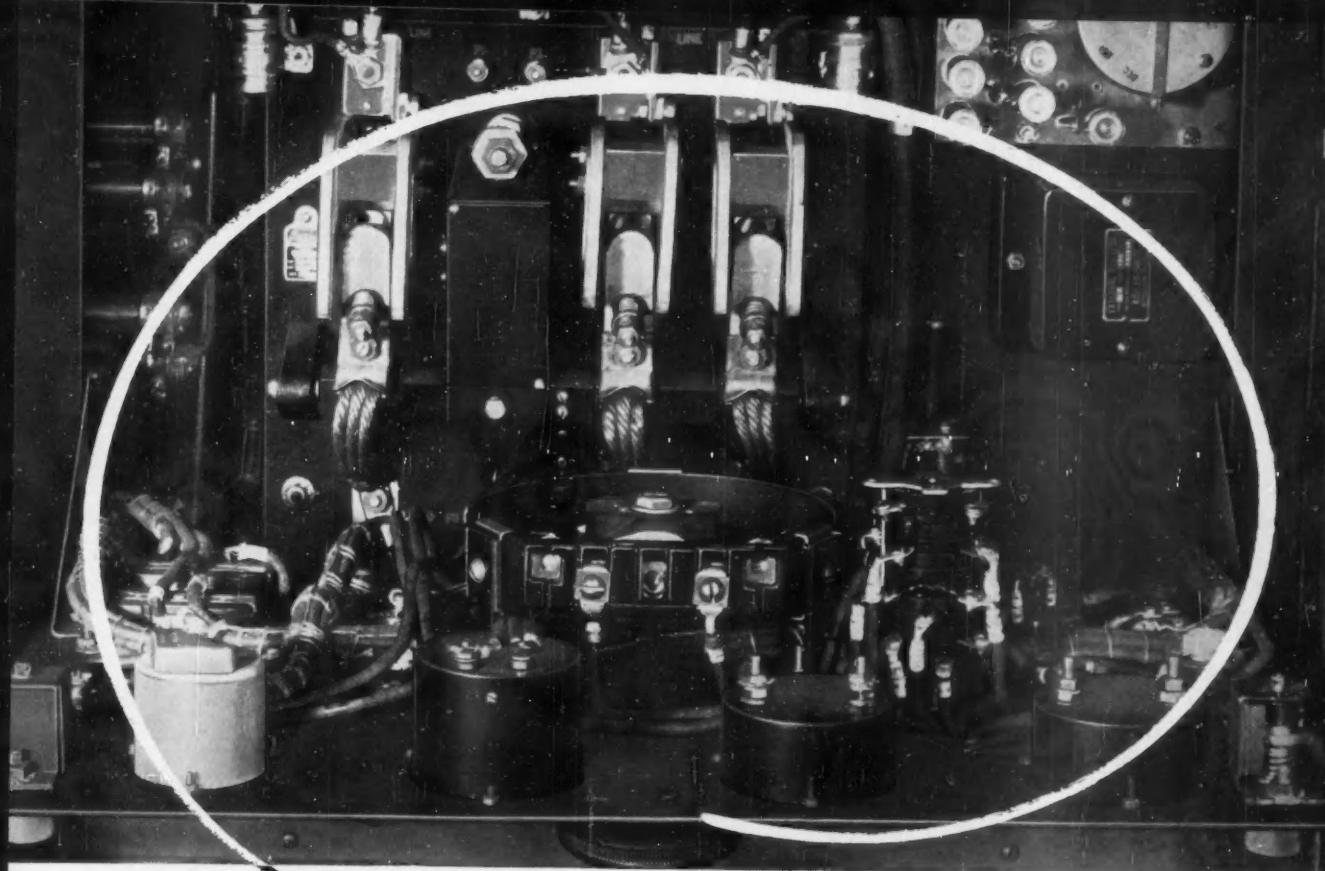
This servo-type data repeater is one of a series now available for flight-test instrumentation. Such units provide remote indication of angular position and of ac and dc voltages. Designed to mount in standard aircraft panels, they are equipped with dials for visual observation or photographic recording. Thermostatically controlled viscous-coupled inertia damping is used to achieve high velocity constants.—Feedback Controls, Inc., Waltham, Mass.

Circle No. 15 on reply card



HUMIDITY SENSOR

Called the Hygropak, this tiny humid-



THIS CONTACTOR ... FITS COMPACTLY IN THE BACK OF THIS PANEL

ASCO Contactor meets Army specs...

compactness, remote control & dependability

To meet the rugged tasks assigned by Army Engineers to a portable, all purpose generator, it must be compact, versatile and dependable. And that is why International Fermont has specified ASCO Contactors on its new 30 KW generator.

Taking up appreciably less space than is normally required by a circuit breaker, the ASCO 3-pole A-C contactor in this installation is connected between the generator and the load. A push button located on the front panel provides convenient remote control of the contactor. The contactor itself is controlled by an overload relay and must interrupt all load currents from a fault current to a short circuit.

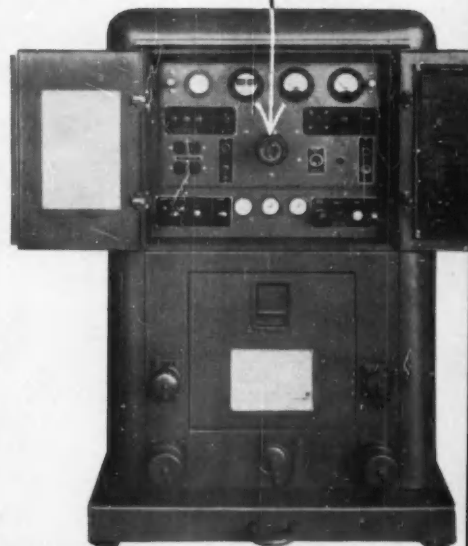
ASCO silver alloy contact design, edge-wise wound copper blowout coils, arc shields, powerful bipolar magnet and rigid

construction of all parts, insure dependable operation. These features aided International Fermont in meeting rigid Army specifications which call for:

- 208 amperes per pole contact rating
- 600 volts A-C maximum • undervoltage release at not less than 48 volts nor more than 84 volts • operating coil 120V — 60 cycles • operation in ambient temperature ranges — 65°F to 125°F.

Write for catalog data on ASCO Contactors: A-C and D-C, normally closed, normally open and double throw, also special applications for sign flashing, street lighting and heater control panels.

Important announcement . . . new ASCO plant now being built in Florham Park, N. J., will double production capacity and greatly extend the range of our research, product development and services.



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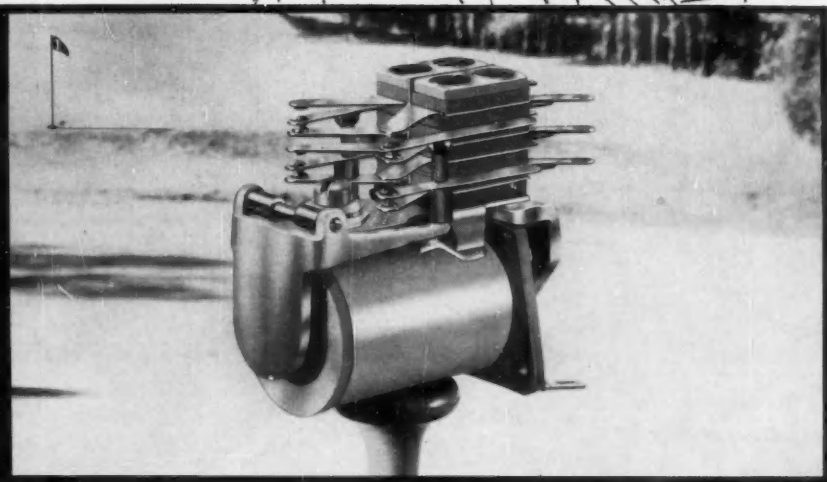
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your**

handicap For lightning calculations of high speed computers and data processing equipment — for lightning responses of guided missiles and modern aircraft, the new Type 9 relay meets all the critical requirements. A miniature telephone-type multi-contact relay, the Type 9 combines speed of action, reliability and high resistance to shock and vibration. It is available in a wide choice of contact materials and with a maximum of 18 springs (9 per pile-up). Springs are phosphor bronze for long life. Each unit is individually adjusted to insure conformance with rigid operating specifications. Type 9 is available as a hermetically sealed unit, measuring 1" x 1 $\frac{1}{8}$ " x 2", only slightly larger than the regular relays.

Work with your man from PHILLIPS on any relay problem — multi-contact, power, hermetically sealed, A.C. or D.C.

HERMETIC SEALS, MULTI-CONTACT, POWER, HERMETICALLY SEALED RELAYS, ACTUATORS

PHILLIPS

PHILLIPS CONTROL CORPORATION . . . JOLIET, ILLINOIS

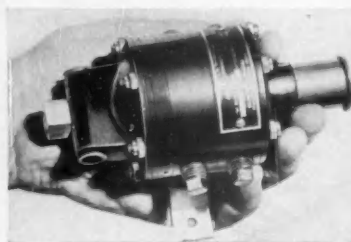
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NEW PRODUCTS

ity sensing element takes advantage of several newly developed coating materials. Applied in thin films over the grid electrodes, these new materials make possible a variety of other elements, some of which decrease their resistance with humidity. Resistances range from as low as a few ohms for use in low voltage bridge-type circuits, to thousands of megohms for use in vacuum-tube type circuits.—Photo-Crystals Inc., Geneva, Ill.

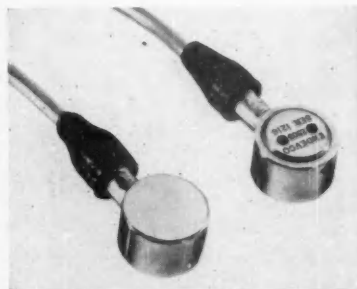
Circle No. 16 on reply card



LOW COST TRANSMITTER

Shown is a 4 $\frac{1}{2}$ -lb differential pressure transmitter for low-cost flow-data transmission. Maker suggests a number of applications where previously control equipment was not considered economical. Unit features a brass body with a neoprene-impregnated nylon diaphragm. Specifications include a maximum working pressure of 150 psi, maximum temperature of 150 deg F, an air consumption of 0.1 scf per min, and an output pressure range of 3 to 15 psi.—Taylor Instrument Cos., Rochester, N. Y.

Circle No. 17 on reply card

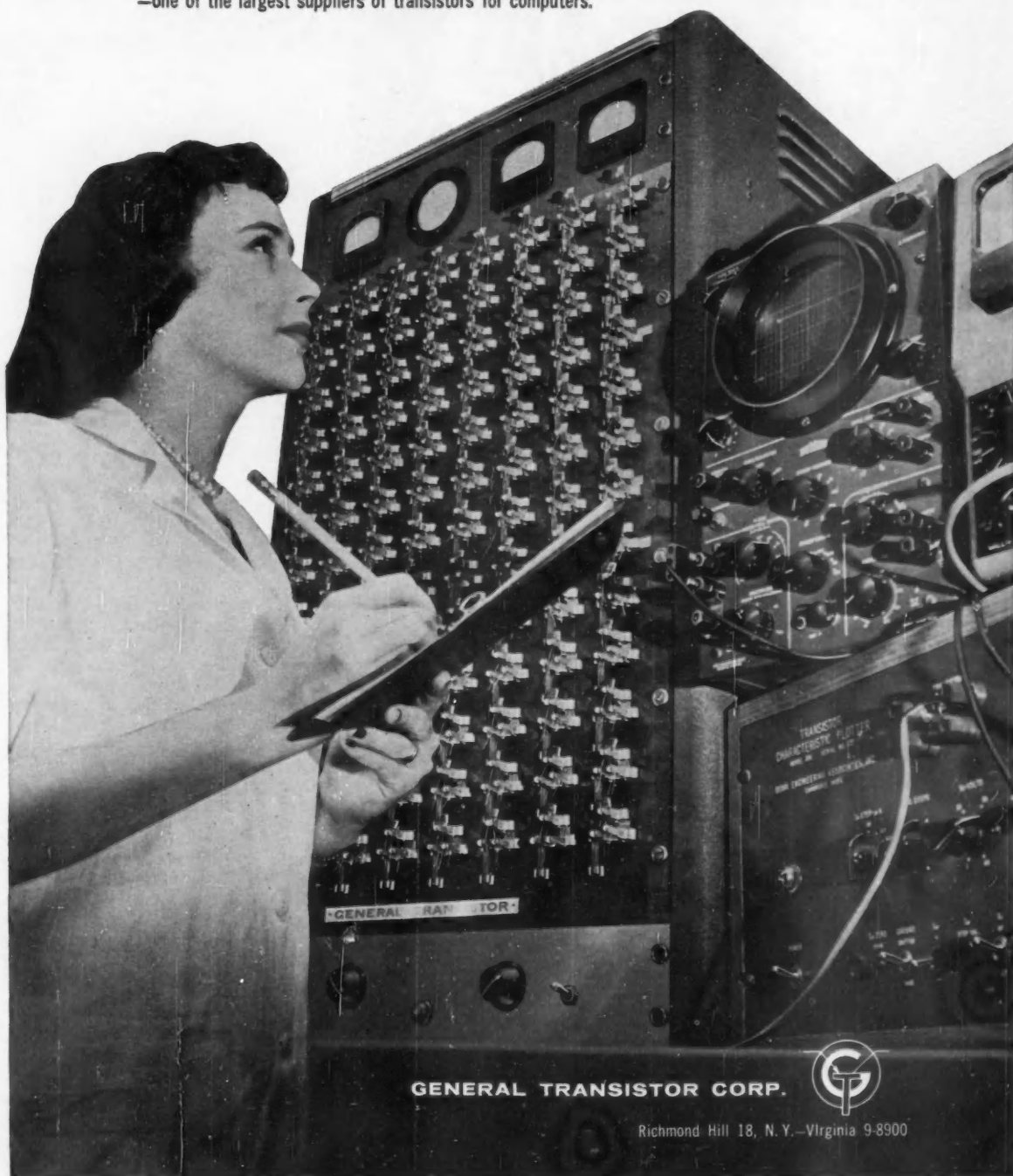


TURBULENCE GAGE

Designed to measure turbulent pressures in wind tunnels, on skin surfaces of models, in gas and hydraulic lines, and in microphone applications, this


GENERAL TRANSISTOR TESTING ASSURES COMPUTER RELIABILITY

Precision manufacturing is not enough! says GT. So General Transistor constantly tests. Along every production step keen eyes, highly skilled technicians, and special instruments check and recheck each transistor. These tests, developed by GT for every specific purpose and characteristic vital to computer reliability assures accuracy and dependability throughout. Whatever your circuit needs, call in General Transistor —one of the largest suppliers of transistors for computers.



GENERAL TRANSISTOR CORP.

Richmond Hill 18, N. Y. — Virginia 9-8900



SAVE PANEL SPACE

with these
CONCENTRIC-SHAFT

PRECISION POTS



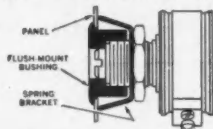
**You can put twice as many precision controls
in the same panel space
with Waters' new concentric-shaft potentiometers.**

Two precision pots • in $\frac{7}{8}$ " or $1\frac{1}{8}$ " size • assembled in tandem • for single-hole or servo mounting • and control by one dual knob • with stops, or for continuous rotation of either or both elements • save vital space • and simplify your designs.

Concentric-shaft, tandem precision potentiometers can be furnished to meet substantially the same specifications as the standard line of Waters RTS $\frac{7}{8}$ and AP1 $\frac{1}{8}$ pots.

Write today for further information, or see your Waters representative.

New Idea in Control Mounting



Now you can easily make any single-hole-mounting pot or trimmer into a flush-mounted or recessed control. Just use the Waters "Pot-Hook"®. Fits any panel up to $\frac{1}{2}$ " thick; available for $\frac{1}{4}$ " or $\frac{1}{8}$ " shaft; can be furnished with "O" ring and gasket for panel seal. Write for data sheet.

Waters
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APPLICATION ENGINEERING OFFICES
IN PRINCIPAL CITIES

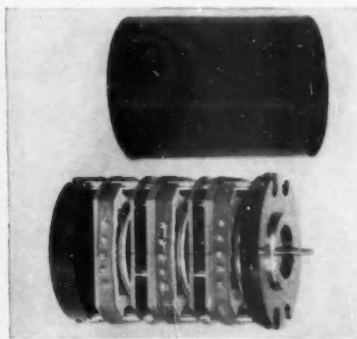
Wayland, Massachusetts
P. O. Box 368, So. Sudbury, Mass.



NEW PRODUCTS

miniature gage provides a minimum sensitivity of 40 mv per psi with a pressure range of 0 to 10 psi. Measuring only $\frac{3}{8}$ in. in diam by $\frac{1}{4}$ in. thick, the gage may be flush-mounted with wax, O-rings, or retaining rings. Frequency range is plus or minus 5 percent from 2 to 10,000 cps.—Endevco Corp., Pasadena, Calif.

Circle No. 18 on reply card



A FLEXIBLE LIGHTWEIGHT

Modular construction of this new analog-to-digital converter permits the addition of binary-coded decimal digits as required. A typical assembly providing three decimal digits weighs only 8 oz and measures $2\frac{1}{2}$ in. in length by 2 in. in diam. Each additional module used to obtain another decimal place adds only $\frac{1}{2}$ in. to the length of the assembly and 2.0 oz to its weight. A unique code and a dual brush system eliminates ambiguity and maintains the accuracy of the system in which it is used.—Federal Telephone & Radio Co., Div. of I T & T Corp., Clifton, N. J.

Circle No. 19 on reply card

INFORMATION DISPLAY INSTRUMENTS

FIVE-IN.-SQ RECORDER

A new self-balancing electronic potentiometer gives a continuous record on a 3-in. strip chart, and matches the company's earlier pneumatic recorder. Offered in either potentiometer or ac bridge models in a 5-in.-sq housing, with or without an indicator, the recorder can be used to

1957 1958 1959 1960 1961

DEPENDABILITY

Guaranteed for 5 years



The best guarantee in the business!

The 401 is so dependable, we're backing it with a *five year guarantee* on all printed wiring and power transformers... and, all other components, including the cathode-ray tube, carry a full one-year guarantee.

DU MONT 401

- IDENTICAL X- AND Y- AMPLIFIERS: Sensitivity, 10 mv/cm. Sinewave response extends flat from dc to 150 kc. Calibration standards built-in for both amplifiers.
- SWEEPS: 18 calibrated ranges extending from 50 ms/cm to 4 us/cm. 3 times sweep expansion available.
- RELATIVE PHASE SHIFT BETWEEN AMPLIFIERS: Easily set for less than 1° at frequencies below 150 kc.
- CATHODE-RAY TUBE: Tight tolerance Type 5ADP, operated at 3000 volts acceleration.
- STABLE OPERATION: Regulation of all power supply potentials, including heaters, provides complete stability.

Best buy in the medium price range—a general-purpose, low-frequency oscillograph for complete, high-quality quantitative measurement. The 401 offers a new high in precision, ease of operation and convenience as a result of “human engineering”—an exclusive of the Du Mont 400 philosophy of instrument design.

WRITE FOR DETAILS.

\$420.00

(slightly higher for 50-cycle areas)

DU MONT® *One of the 400 Series*

TECHNICAL SALES DEPARTMENT, ALLEN B. DU MONT LABORATORIES, INC. • CLIFTON, N. J.

JANUARY 1957

129

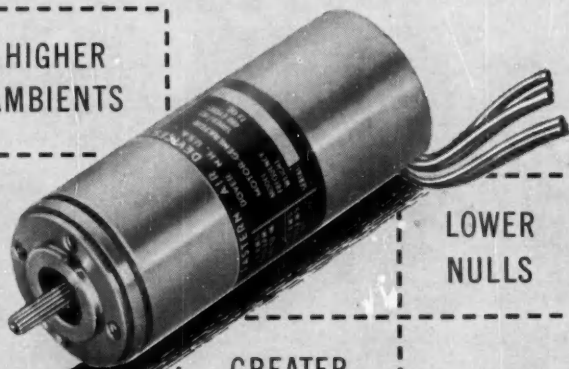


announces
an unusually precise

SERVOMOTOR- TACHOMETER GENERATOR

HIGHER
AMBIENTS

SIZE 11
SJ1HLX7
(Actual size)



LOWER
NULLS

GREATER
RUGGEDNESS

for
**INSTRUMENTATION
FIRE CONTROL
AUTOPILOTS
MISSILES
COMPUTERS**

FEATURES:

Zero Speed Voltage (RMS) 8.0 mv in phase
15.0 mv quadrature
19.0 mv total

Max Ambient Temp. 150°C

Linearity 0.5% to 3600 rpm

Output Gradient Phase Shift 0.5V/1000 rpm (min.) $\pm 10\%$

Servo motor meets Bu. Ord. MK-14 specifications.

Equipped with precision gearhead for lower backlash.

Rugged, one-piece assembly.

WRITE for complete detailed information

EASTERN AIR DEVICES, INC.

SOLVING SPECIAL PROBLEMS IS ROUTINE AT EAD

375 CENTRAL AVENUE • DOVER, NEW HAMPSHIRE

NEW PRODUCTS

measure temperature, flow, speed, pH, smoke density, etc. Plug-in construction simplifies maintenance. — The Bristol Co., Waterbury, Conn.

Circle No. 20 on reply card



GRAVITY INDICATOR

This new direct reading, fully automatic specific gravity indicator is said to have an accuracy of 0.001 sp gr units with interpolation to 0.0005 units. All functional parts of the indicator are mounted on the rear of the panel shown above. The instrument operates on the principle of a differential bubbler and has two static pickup tubes within the vessel containing liquid to be tested. Two other tubes are installed in a small reference tank within the instrument. Indicating system consists of a combined vertical and inclined manometer with an adjustable well and safety overflow. — Petrometer Corp., Long Island City, N. Y.

Circle No. 21 on reply card



NEW FEATURES ADDED

This company's line of pulse rate converters has been expanded to include several new models. Basically, the units measure the frequency of

A MIDWESTERN OSCILLOGRAPH for every recording application

This tabulation shows the many types of
MIDWESTERN recording oscillographs
available today.



S P E C S	Model	Maximum Trace Capacity (1)	Dimensions inches (2)	Weight Pounds (3)	Record Speed Range Inches/Sec	Record Width Inches	Magazine Capacity Feet (5)	Power Requirements	Timing Lines Sec/Line	Optical Arm Inches	Temperature Range °F	Maximum Acceleration G's	Model
	560	14	5 1/4 x 6 1/4 x 7 1/2	9	.375 To 8	3.625	50	28 Volts d.c. 3 Amps Max.	.01 And/Or .10	6.921	0 to + 100	20 (8)	560
	580		7 1/4 x 7 1/4 x 13 1/2	22.5	.50 To 44.75 (4)		100	28 Volts d.c. 15 Amps Max.		7.375	-65 to + 100	20	580
	581		7 1/4 x 7 1/4 x 15 1/4	28.5									581
	544	36	11 1/2 x 12 1/2 x 20	75	1 To 50	8	200	28 Volts d.c. 10 Amps Max. or 115 Volts, 60 cps 3 Amps Max.		14.400	+ 32 to + 100	1	544
	570	50	11 1/2 x 16 1/2 x 20	97	50	12							570
	590	36	11 x 11 1/2 x 21 1/2	90	.002 To 129.9	7	150	(6)	(7)	11.00	-65 to + 100	15	590
	591	50	11 1/4 x 16 1/2 x 24 1/4	130		12	250						591
F E A T U R E S	Model	Record Numbering	Trace Identification	Automatic Record Length	Timing Line Intensity Control	Galvo Lamp Intensity Control	Record Used Indicator	Recording Malfunction Indicator	Galvo Lamp Burnout Indicator	Timing Lamp Burnout Indicator	Rotary Scanning	Remote Control	Model
	560	—	—	—	—	✓	—	—	—	—	—	—	560
	580	—	✓	—	✓	✓	✓	—	✓	✓	—	✓	580
	581	✓	✓	✓	✓	✓	✓	✓	✓	✓	—	✓	581
	544	✓	✓	✓	(8)	✓	✓	✓	✓	(8)	✓	✓	544
	570	✓	✓	✓		✓	✓	✓	✓		✓	✓	570
	590	✓	✓	✓		✓	✓	✓	✓		✓	✓	590
	591	✓	✓	✓		✓	✓	✓	✓		✓	✓	591

NOTES (1) Using MIDWESTERN 102 Galvanometers.
(2) Dimensions include all external controls and fittings but do not include mating electrical connectors or shock-mount base.
(3) Weight does not include shock-mount base.
(4) A low speed version of these models is available with all recording speeds reduced by a factor of 60.
(5) Listed magazine capacities are with Kodak Linagraph #809 Paper. Other standard recording paper or film may also be used. Larger capacity magazines are available for the 580, 581, 590, and 591 Models.
(6) May be operated from 28 volts dc, 15 amps max.; or 115 volts, 60 or

400 cps single phase, 5 amps max. by means of interchangeable plug-in power supply units.
(7) Timing lines of .001 and/or .01; .01 and/or .10; or .10 and/or 1.0 seconds intervals, by means of interchangeable plug-in units.
(8) A special version of this model is available which will withstand shock accelerations in excess of 1000 gravities.
(9) Timing lines are produced by electronic flasher-tubes. Due to their much longer operating life, warning indicators are not required; and because of their flash illumination characteristic, intensity adjustments are not necessary.

for complete details on the above oscillographs —
and other MIDWESTERN test recording
instruments and servo components — write

MIDWESTERN INSTRUMENTS

41st and Sheridan Road

Tulsa, Oklahoma

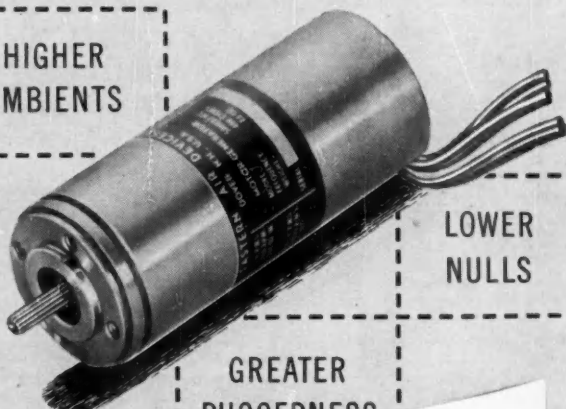


announces
an unusually precise

SERVOMOTOR- TACHOMETER GENERATOR

HIGHER
AMBIENTS

SIZE 11
SJ1HLX7
(Actual size)



LOWER
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GREATER
RUGGEDNESS

for
**INSTRUMENTATION
FIRE CONTROL
AUTOPILOTS
MISSILES
COMPUTERS**

FEATURES:

- Zero Speed Voltage (RMS) 8.0 mv in phase
15.0 mv quadrature
19.0 mv total
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- Output Gradient Phase Shift 0.5V/1000 rpm (min.) $\pm 10\%$
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WRITE for complete detailed information

EASTERN AIR DEVICES, INC.

SOLVING SPECIAL PROBLEMS IS ROUTINE AT EAD

375 CENTRAL AVENUE • DOVER, NEW HAMPSHIRE

NEW PRODUCTS

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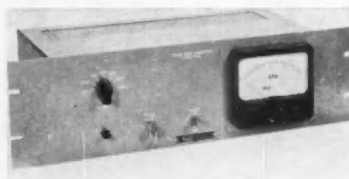
Circle No. 20 on reply card



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Circle No. 21 on reply card



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	544	30	11 1/2 x 12 1/2 x 20	75	1 To 50	8	200	20 Volts d.c. 10 Amps Max. or 115 Volts, 60 cps 3 Amps Max.	(7)	14.469	+ 32 to + 100	1	544
	570	50	11 1/2 x 16 1/2 x 20	97	50	12							570
	590	36	11 x 11 1/2 x 21 1/2	90	.982 To 129.9	7	150			11.08	-65 to + 100	15	590
	591	50	11 1/2 x 16 1/2 x 24 1/2	130		12	250	(6)					591
F E A T U R E S	Model	Record Numbering	Trace Identification	Automatic Record Length	Timing Line Intensity Control	Galvo Lamp Intensity Control	Record Used Indicator	Recording Malfunction Indicator	Galvo Lamp Burnout Indicator	Timing Lamp Burnout Indicator	Rotary Scanning	Remote Control	Model
	560	—	—	—	—	✓	—	—	—	—	—	—	560
	590	—	✓	—	✓	✓	✓	—	✓	✓	—	✓	590
	581	✓	✓	✓	✓	✓	✓	✓	✓	✓	—	✓	581
	544	✓	✓	✓	(8)	✓	✓	✓	✓	(8)	✓	✓	544
	570	✓	✓	✓		✓	✓	✓	✓		✓	✓	570
	590	✓	✓	✓		✓	✓	✓	✓		✓	✓	590
	591	✓	✓	✓		✓	✓	✓	✓		✓	✓	591

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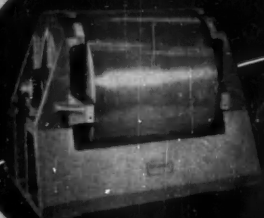
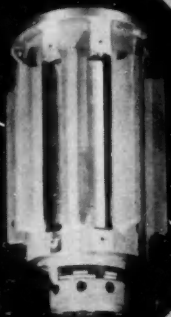
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and other MIDWESTERN test recording
instruments and servo components — write

MIDWESTERN INSTRUMENTS

41st and Sheridan Road

Tulsa, Oklahoma

You Can't Beat a Bryant Drum



Bryant magnetic Drums

for semi-permanent storage of data in
digital computers or for use as delay lines

- Designed to purchaser's requirements
- Guaranteed accuracy of drum runout .00010" T.I.R. or less
- Air bearings or super-precision ball bearings
- Belt drive or integral motor drive, speeds to 100,000 RPM
- Capacities to 5,000,000 bits
- Vertical or horizontal housing
- Head mounting surfaces to suit
- High density magnetic oxide or electroplated magnetic alloy coating

High Speed Motors, Spindles and Drums

Bryant designs and manufactures electro-mechanical components for precision operation up to 200,000 RPM, to your requirements. If you have a problem in applying high speed rotating equipment to your product, write Bryant today.

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DIVISION OF BRYANT CHUCKING GRINDER CO.

NEW PRODUCTS

turbine flowmeters or tachometer generators, and convert them to proportional dc signals. Models are now available with up to 10 input channels, each of which can be selected for display on a single built-in indicator. Voltage output to operate electronic indicators, recorders, or controllers is now included on all models. Input frequency range is 5 to 3,000 cps. Five internal calibration frequencies are provided. Waugh Engineering Co., Van Nuys, Calif.

Circle No. 22 on reply card



SPEEDS READOUT

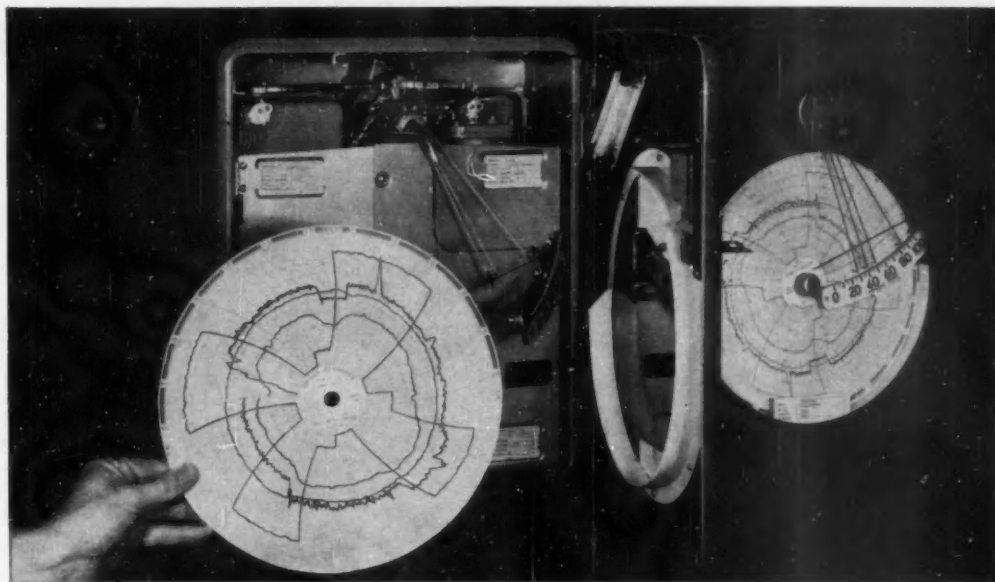
Shown is a complete Model 100 computer readout designed to minimize storage time in electronic computer readout registers. Heart of the unit is the Charactron tube (CtE, Dec. '56, p. 148). Other components are the necessary circuitry, a high-voltage supply, digital-to-analog converters, a power supply, and a camera recorder. The face of the tube is positioned so that the letters and numbers reproduced can be recorded by the specially designed 35-mm camera.—Stromberg Carlson Div. of General Dynamics Corp., San Diego, Calif.

Circle No. 23 on reply card



SPEED METER

This compact unit, dubbed the MF-2 Speed-Feed Meter, measures and in-



Faithfully yours -

Clear, Continuous Records without Poisoning ... on the New Bailey Recorder

★ Faithful chart records of measured variables are the key to a meaningful, dependable analysis of operating trends and conditions. Money spent for more accurate metering, for faster response, is money down the drain—unless it's matched with chart records that are equally accurate

That's why these features of the new Bailey Recorder are important to you:

1. Bailey's exclusive sealed capillary-action inking system maintains continuous flow to the pen tip, and traces sharp, opaque, quick-drying records. "Poisoning" of intersecting records is practically eliminated; no blots or smears during operation or chart changing.
2. Pens are mounted on concentric centers, trace on parallel time arcs only $42/1000''$ apart. This simplifies analysis of two or more records.
3. Interchangeable plug-in receiver units permit practically limitless record-grouping combinations.

Write for Product Specification E12-5 and actual chart sample.

P52-41



ONLY BAILEY OFFERS ALL THESE ADVANTAGES IN A SINGLE RECORDER

- Pre-calibrated plug-in receiver units
- Up to four pneumatic or electronic receivers—or two receivers and two integrators
- Any four variables on one chart—easily read and interpreted
- A full year's ink supply at one loading
- Faster shipment—from stock
- Minimum inventory of parts
- Minimum instrument investment for process cycle expansion or alteration

BAILEY

METER COMPANY

1079 IVANHOE ROAD

CLEVELAND 10, OHIO

Controls for Power and Process



Controls for
TEMPERATURE
PRESSURE
GAS ANALYSIS
FLOW · LEVEL ·
RATIO · DENSITY

Lepel

HIGH FREQUENCY Induction HEATING UNITS

BRAZING
HARDENING
BOMBARDING
SOLDERING
ANNEALING
MELTING

The Lepel line of induction heating units represents the most advanced thought in the field of electronics as well as the most practical and efficient source of heat yet developed for industrial heating. With a background of half a century of electrical and metallurgical experience, the name Lepel has become the symbol for quality in induction heating equipment embodying the highest standards of engineering achievement, dependable low cost operation and safety.

If you are interested in the application of induction heating you are invited to send samples of the work with specifications of the operations to be performed. Our engineers will process these samples and return the completed job with full data and recommendations without any cost or obligation.

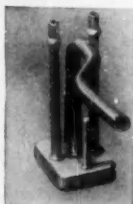
TYPICAL INDUCTION HEATING APPLICATIONS



The simultaneous soldering of a group of components within one load coil is an ideal application for induction heating. The assemblies consist of mounting studs and tubes, inserted into a machined part together with preformed solder rings. The heating is done so rapidly that there is practically no scaling or discoloration.



A Lepel installation at Federal Telephone and Radio Co. shown soldering transformer terminals. A precision operation made so simple that even unskilled operators can achieve excellent results on a production basis.



**Electronic Tube Generators—1 KW; 2½ KW;
5 KW; 10 KW; 20 KW; 30 KW; 50 KW; 75 KW; 100 KW.
Spark Gap Converters 2 KW; 4 KW; 7½ KW; 15 KW; 30 KW.**

WRITE FOR THE NEW LEPEL CATALOG . . . 36 illustrated pages packed with valuable information.



All Lepel equipment is certified to comply with the requirements of the Federal Communications Commission.

LEPEL HIGH FREQUENCY LABORATORIES, INC.

55th STREET and 37th AVENUE, WOODSIDE 77, NEW YORK CITY, N. Y.

NEW PRODUCTS

indicates linear rates of travel and rpm. Said to be suitable for both laboratory and industrial use, the unit converts travel rates into electrical signals. A large illuminated meter gives the reading directly, with pushbutton selection of four scale ranges from 0-1 to 0-125 in. per min. Models are also available with combinations of linear rate and rpm scales. The fixed tachometer pickup has no moving parts and is easily mounted near a gear on the shaft being measured. A hand-held tachometer pickup is optional.—Maico Co., Inc., Minneapolis, Minn.

Circle No. 24 on reply card

CONTROL DEVICES



SLIDE-OUT CHASSIS

Recent changes in this company's electronic timer include an improved housing for various mounting conditions, and a new slide-out chassis with plug-in tube and condenser. Other features: readily accessible terminals, isolated load contacts, and a large easy-to-read dial.—General Control Co., Boston, Mass.

Circle No. 25 on reply card

FLEXIBLE TIME CYCLE

Called the Intermatic "Cycler-12", a new timer provides a variety of repetitive timings. The unit is recommended for use on fans, pumps, and other equipment operating on timed cycles. "On" operations may range

ANOTHER RED HOT PROBLEM

SOLVED BY

Taylor



Accurate measurement of process pressures at temperatures up to 1500° F.

THE RED portion of this picture shows another example of Taylor ingenuity at work. It's a volumetric pressure measuring system for use at extremely high temperatures. Although designed primarily for atomic energy applications, it has since been adapted for a variety of applications in measuring pressures of liquid metals.

Built to meet tremendously severe requirements, this system will measure pressures at temperatures up to 1500°F., to the accuracies usually associated with measurement at atmospheric temperatures. And it will measure short ranges that would be subject to considerable error with conventional systems.

Seventy-five of these units have been installed to date, and all are working satisfactorily . . . a tribute indeed to the vision and ingenuity of Taylor engineers and the dependability of instrumentation bearing the Taylor name.

Whether or not *your* instrument problem has anything to do with measuring pressures of molten metals, it's probable that we can find the answer. Just call your Taylor Field Engineer, or write Taylor Instrument Companies, Rochester, N. Y., or Toronto, Canada.

Any length of span is permissible between the limits of 50 and 600 psi. Suppression of 100% up to 0-300 psi. The system shown uses a 5-ply corrugated diaphragm, 4" O.D. In addition to the Taylor indicator shown above, it can be used with recorders, controllers and dial type indicators.

Instruments for indicating, recording and controlling temperature, pressure, flow, liquid level, speed, density, load and humidity.

Taylor Instruments

— MEAN —

ACCURACY FIRST

IN HOME AND INDUSTRY



What makes a wind tunnel *commercially* successful?

If the term "commercial success" could be applied to aeronautical test facilities, it would be on the basis of the data-dollar ratio. How much *valid* data is produced *per dollar of facility . . . per engineering hour.*

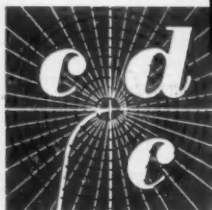
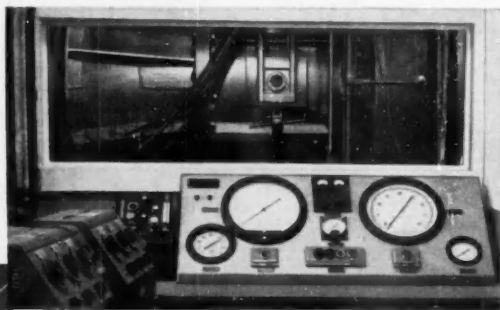
CompuDyne Control Systems, employing computer-dynamic techniques, are achieving increased output of *valid data* . . . by establishing and programming the test process.

CompuDyne Systems were developed for high-speed, dynamic control of transients . . . the basic control problem of test facilities. They attain steady-state control of test conditions . . . step, ramp or otherwise program variables . . . at higher

speeds, with greater accuracy than ever before possible.

CompuDyne Control Systems encompass the full control loop . . . from sensor to final control element. They are pre-tested and performance-guaranteed on the basis of analog simulation of the control system and your process *in operation.* CompuDyne Control Systems are applicable to new installations or for improved performance of existing facilities.

Write or telephone for full information. Informative new bulletin entitled, "*VALID DATA . . . economically produced by dynamic process control*" will be sent to you upon request.



CompuDyne Control is a trademark of cdc control services, inc.

For Test Facilities . . . Typical CompuDyne Control Systems

Aircraft Engines & Components	Continuous Wind Tunnel
Aircraft Accessories	Dynamic Structural Loading
Fuel System Components	Altitude Chamber
Blowdown Wind Tunnel	Compressor Surge

Representatives in major cities.

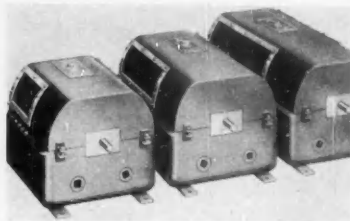
cdc control services, inc.

402 S. Warminster Road • Hatboro, Pennsylvania

NEW PRODUCTS

from 10 to 670 sec; "off" operations may be as short as 50 or as long as 710 sec. The time dial will accommodate up to 12 sets of trippers, making the unit adjustable through 90 percent of its 12-min range.—International Register Co., Chicago, Ill.

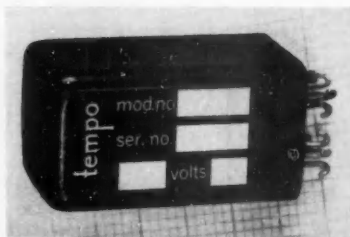
Circle No. 26 on reply card



CAM LIMIT SWITCHES

These cam-operated, rotating limit switches permit precise synchronization of multiple operations. Units feature a positive micrometer screw adjustment of each individual contact assembly in relation to its cam. Adjustment is simple. It can be made with a screwdriver from the outside while the switch is in motion. Sizes include a five-, nine-, and a 12-cam model. All contacts have a 15-amp capacity. — Clark Controller Co., Cleveland, O.

Circle No. 27 on reply card



NO MOVING PARTS

Miniature time delay relays weigh less than 2 oz, measure 1 in. sq by 1½ in. long, and are available with delay periods from 0.1 sec to 5.0 sec. Both ac and dc units are offered. The dc inputs range from 28 to 150 volts; ac, from 26 to 116 volts, 60 to 400 cps. High accuracy makes these relays suitable for aircraft and missile instrumentation, machine tool control circuits, electronic computers, and many other applications.—Tempo Instrument Co., Hempstead, N. Y.

Circle No. 28 on reply card



U. S. Air Force Photo

Designed basically for night photographic work, the Martin RB-57 is employed by USAF TAC, powered by two Wright J-65 jet engines.

WADC'S WEAPONS GUIDANCE LABORATORY GIVES ACCURACY TO AIR FORCE BOMBS, MISSILES AND AIRCRAFT

The Weapons Guidance Laboratory at the Air Research and Development Command's Wright Air Development Center performs applied research and development of all Air Force weapons guidance equipment.

Included under this broad category are airborne bombing systems and equipment, weapon defense systems, offensive fire control systems, missile guidance equipment, electronic jamming systems, chaff systems, navigation systems, manual navigation aids and special test equipment peculiar to the requirements of the weapons guidance systems or equipment. In addition, all components of the foregoing are the province of this

laboratory. The facilities available for these studies include various gun ranges, temperature and altitude chambers and other specialized test and evaluation installations.

Weapons Guidance is one of the laboratories that form the Wright Air Development Center. WADC, in turn, is the largest Center under the Air Research and Development Command. At its location at Wright-Patterson Air Force Base, Ohio, upward of 10,000 military and civilian workers are engaged in research, development and testing of aircraft, guided missiles and all types of associated flight and ground equipment.

This is one of a series of ads on the technical activities of the Department of Defense.



FORD INSTRUMENT COMPANY

DIVISION OF SPERRY RAND CORPORATION

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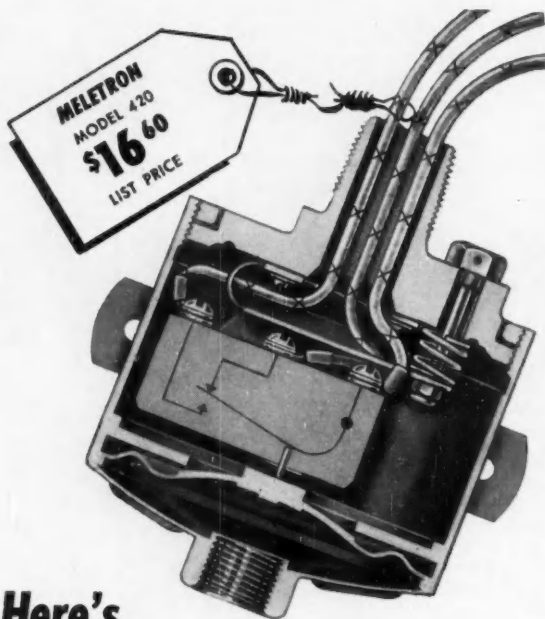
105

ENGINEERS


of unusual abilities can find a future at FORD INSTRUMENT COMPANY. Write for information.



Engineer of Ford Instrument Company checking unit designed by the Company for the Air Force to be certain that its magnetic effects will not affect other instruments in the aircraft.



Here's the Simplest Diaphragm Pressure Switch

WE BUILD IN	WE DON'T USE
EXTREME ACCURACY and DEPENDABILITY maintained during operating life due to direct acting design	LINKAGES & BEARINGS  which, as they wear, make the setting of the pressure switch drift.
OPERATION IN ANY POSITION which saves the installation costs encountered in mounting a switch that uses liquid switching elements.	LIQUID SWITCHING ELEMENTS  which make the switch difficult to mount and very critical to vibration.
IMMUNITY TO VIBRATION you can mount the switch directly on your vibrating or moving equipment.	ACCORDION DIAPHRAGMS  which make the pressure switch sensitive to vibration.

To get complete specifications and operating data ask for bulletins 420- 421

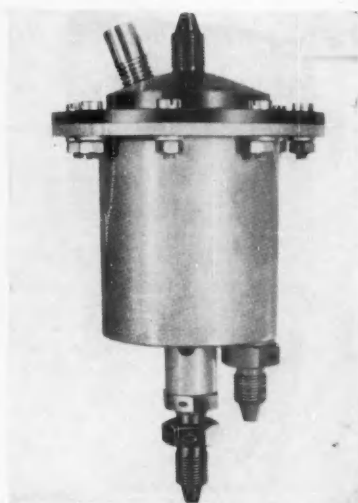
BARKSDALE VALVES



PRESSURE SWITCH DIVISION

5125 Alcoa Avenue, Los Angeles 58, California

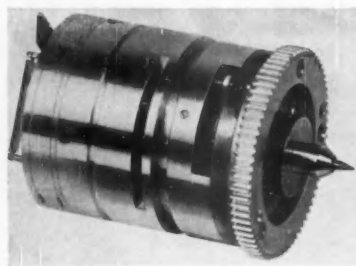
NEW PRODUCTS



RATIO CONTROLLER

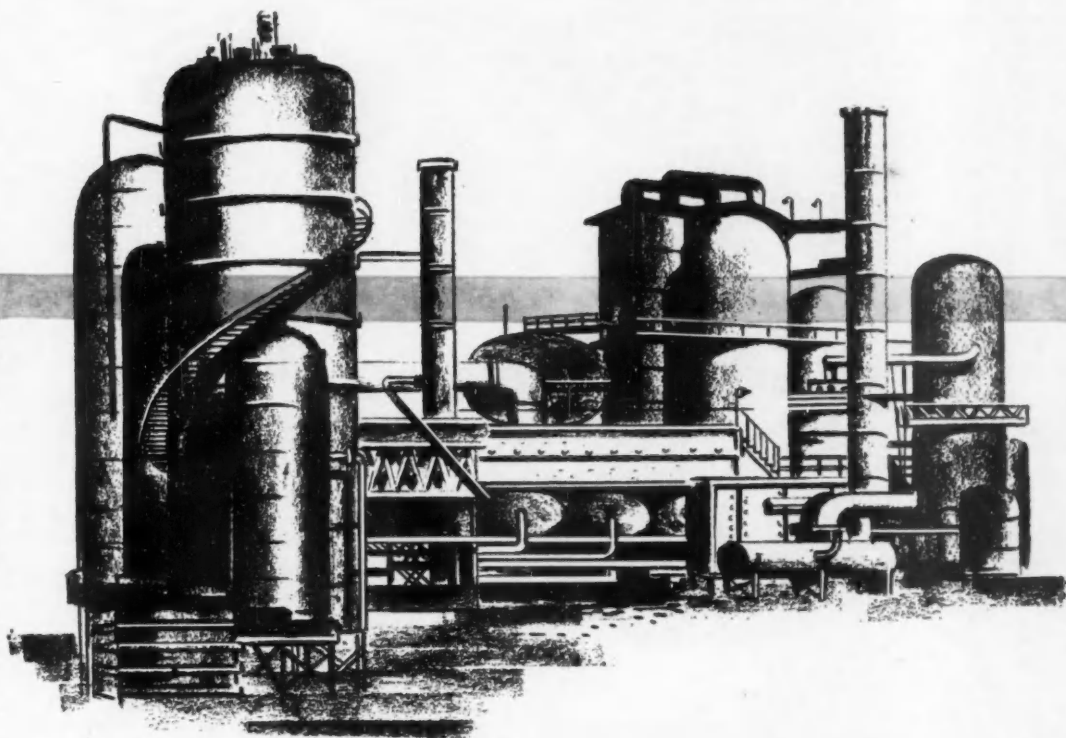
This new pressure ratio controller was designed to get maximum efficiency from a cold air turbine. A twin-bellows assembly with an absolute zero pressure datum controls the air bleed from a small jet. This air regulates a diaphragm-powered pneumatic valve. In a typical installation, it limits pressure ratio by either controlling the supply pressure or by varying back pressure. Unit weighs 1 lb and is only 3 in. in diam at the flange.—Gloster Aircraft Co., Ltd., Gloster, England.

Circle No. 29 on reply card



MODULAR DESIGN

Developed for use in weapons, this rugged timer consists of three cylindrical components mounted on a single axis. They include a time interval measuring unit, a driving unit or main-spring, and a control unit. Main-springs are available in several sizes to provide different operating torques for the control unit, and different operating periods for the timer. Maker



FOR VITAL FLOW CONTROL

WHETHER you're developing a new process or modernizing an old one—investigate the unique characteristics of the *bearingless Pottermeter*.

This electronic flowmeter—easily installed in any type of piping to operate at any angle, at any pressure and at temperatures from -450 to $+1200^{\circ}\text{F}$, measures flow of any liquid with an accuracy of $\pm\frac{1}{2}$ of 1%.

Pottermeters are available to measure flows as low as 0.07 GPM or as high as 3,000 GPM. The inherently linear output of the Pottermeter makes it ideal for systems to control either flow rate or total flow.



Find out how the bearingless "floating rotor" used in the Pottermeter can give you more precise flow measurement, longer trouble-free service life, and more accurate flow control.

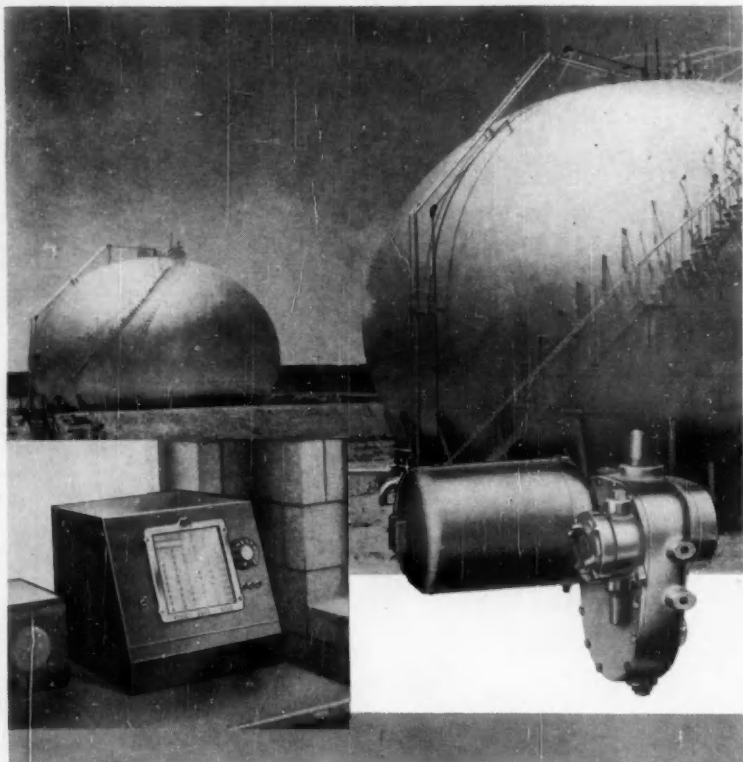
Write for Bulletin PS-1

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POTTER AERONAUTICAL COMPANY

Route 22 • Union, New Jersey • Phone MURdock 6-3010

Makers of "Potter Engineered" products



"Varec" PULSE CODE KEEPS "TAB" ON OKAN PIPELINE

Keeping a pipeline flowing smoothly is a mighty big job . . . that's why OKAN PIPELINE wants the latest in automatic equipment to speed its work. An important part of this equipment is the "Varec" PULSE CODE Telemetering System, which signals the liquid level of storage tanks at terminals and along the line. In addition to this function, it turns valves on and off by remote control. "Varec" PULSE CODE operates over long distances, giving an accurate signal. It requires only a simple metallic pair for a communication link. It supplies a fast

reading in the record time of 5 seconds. There is also a unique feature for remote control of valves, pumps, etc., which confirms that the proper selection of remote function has been made and indicates the status of the selected function. The operator may now change the status and receive a confirmation that it has been completed.

You may want to cut your operating costs by using a "Varec" PULSE CODE System. Equipment for reporting either spot or average temperature, in addition to liquid level, is now available.

Write for "Varec" Bulletin CP-3011 for full details on
"Varec" PULSE CODE Telemetering.

961-17

THE VAPOR RECOVERY SYSTEMS COMPANY



Compton, California, U. S. A.

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NEW PRODUCTS

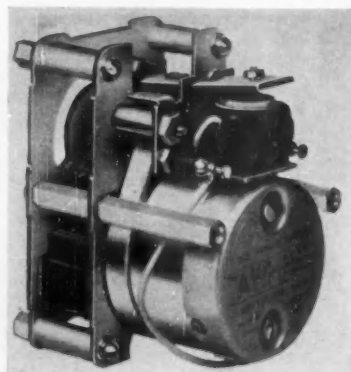
claims the entire mechanism withstands accelerations up to 3,000 g's, and suffers only slight reduction in accuracy when rotated on its own axis at high speed.—Allied Products Div., Hamilton Watch Co., Lancaster, Pa.

Circle No. 30 on reply card

HIGH PRESSURE REGULATOR

With nominal inlet pressures up to 6,000 psi, a new high-flow regulator is said to accurately regulate output pressures between 0 and 5,000 psi. The unit has a burst maximum of 15,000 psi. Other features: a maximum handle torque of 30 in.-lb due to a planetary gear system, and easy access to the internal valve and filter. The regulator will handle air, nitrogen, helium, and gaseous oxygen. An internal relief valve is adjustable over the entire output pressure range.—Accessory Products Corp., Whittier, Calif.

Circle No. 31 on reply card



TIME DELAY RELAYS

Shown is a dc time delay relay with its dust cover removed. A single switch unit, it is designed for reliable operation under all normal conditions experienced in aircraft, military, and commercial use. Units are available with standard or chronometrically governed dc motors. Other models are also available for 115-volt, 60-cycle or 400-cycle operation. Clutch coils for operation over the same voltage range as the motor are provided for all models except the 400-cycle units, which are supplied with dc clutch coils.—A. W. Haydon Co., Waterbury, Conn.

Circle No. 32 on reply card

FOR THE THIRD CONSECUTIVE YEAR

ENGINEERS RATE LAMBDA FIRST

in all
**Power Supply
Surveys**

Every independent study of power supply preferences has shown an overwhelming vote for Lambda. In the most recent survey, made by a leading electronics publication, engineers who specify power supplies choose Lambda by more than 2½ times over the next identified manufacturer. This is the greatest margin of preference yet. Here is additional proof that the more opportunities users of power supplies have to try Lambda equipment for themselves, the more they recognize the superiority of these outstanding units.

We suggest that you inspect Lambda power supplies in use in your own area. We will be happy to provide names of nearby users. Ask the candid opinion of the men who work with this precision-engineered equipment daily.

L A M B D A

MANUFACTURER "B"

MANUFACTURER "C"

MANUFACTURER "D"

MANUFACTURER "E"



QUALITY CONTROL assures you of long, dependable service from these assembly-line-produced power supplies.



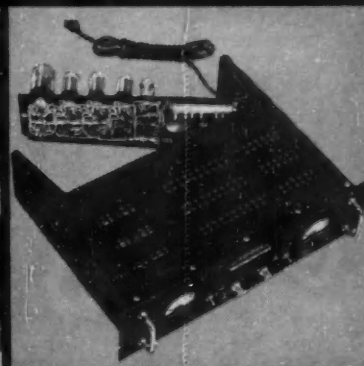
HERMETIC SEALING PROCESS provides for complete quality control. Lambda makes all its own transformers.



MECHANICAL INSPECTION at every relevant point means trouble-free operation for you.



ELECTRONIC INSPECTION is designed to provide consistent quality and eliminate in-service down-time.



TYPICAL NEW LAMBDA "COM-PAK" MODEL (200-400-800 MA units) occupies a minimum amount of space, delivers maximum performance, is easy to service and maintain.



LAMBDA ELECTRONICS CORP.

The first name in power supplies

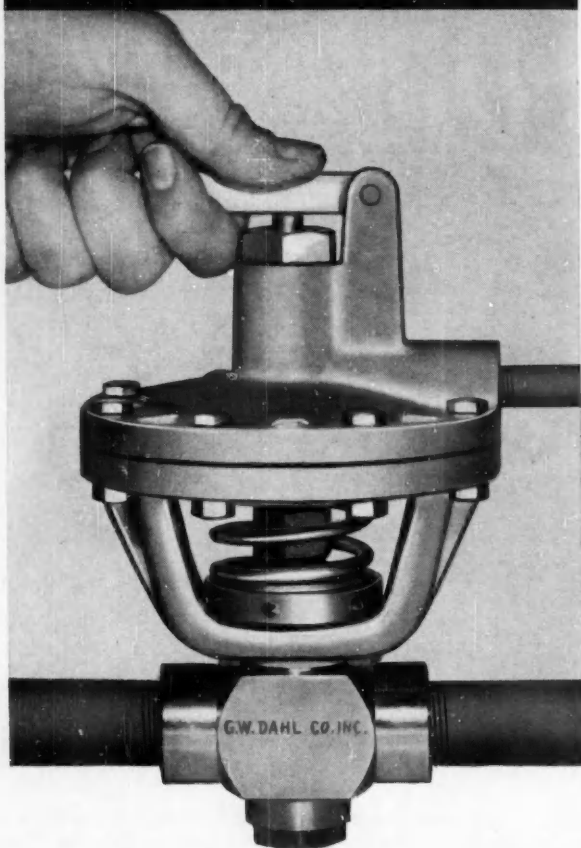
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Just off the presses.
Illustrations and
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"MANUAL RESET"



A "BLOCK-SAFE" VALVE

Wherever control or supply air to pneumatically operated instruments and valves operating on dangerous or toxic process flows, or the process flow itself, must be blocked for safety, "manual reset" valves will provide safe, vigilant guarding of lives and property.

They will snapact at a predetermined falling control pressure to either vent diaphragm air or lock it at the desired pressure.

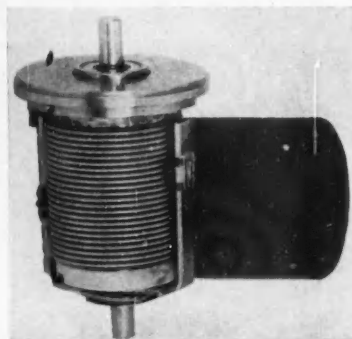
Upon return of control air they must be manually reset. Nothing is left to chance.

Available in various materials in sizes up to 1" IPS.

For prices, further technical information, and our representative's address in your area, inquire directly to our home office.

George W. DAHL Company
BRISTOL, RHODE ISLAND

NEW PRODUCTS



NEW PRECISION POT

This new pot, 2 in. in diam, is said to provide independent linearity as close as 0.01 percent. For stability, the resistance coil is externally wound on a nonhygroscopic ceramic core which is chemically inert and dimensionally stable. Units can be supplied with two gangs of 10 turns, a single gang of 15 turns, and many other combinations. Metal-to-metal traveling nut stops withstand 500 oz-in. Electrical angle is 3,600 deg with 90 deg overtravel at each end.—Littion Industries, Mount Vernon, N. Y.

Circle No. 33 on reply card



NEW CLOCK MOVEMENT

A 2½-in. fully enclosed clock movement features a synchronous electric motor drive. Said to be one of the smallest and lightest movements available, the unit has hour-, minute-, and second-hand arbors and is equipped with a setting knob located on the back of the case. It can be supplied for either 115- or 230-vac operation.—Haydon Mfg. Co., Torrington, Conn.

Circle No. 34 on reply card

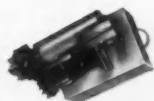


you can have the advantages of plug mounting in all these Automatic Electric relays



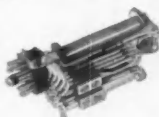
CLASS A:

The "all-purpose" relay for use where first cost is important. Gives long, dependable service. Size: $4\frac{3}{8}" \times 2\frac{3}{8}" \times 1\frac{1}{8}"$.



CLASS B:

Made for extremes of long service life and dependability — often exceeding 400 million operations! Size: $4\frac{3}{8}" \times 2\frac{3}{8}" \times 1\frac{1}{4}"$.



CLASS F:

Low operating power makes this relay especially desirable in a.c. circuits where relays function without specified operate or release time delays. Size: $4\frac{3}{8}" \times 1\frac{1}{8}" \times 1\frac{1}{4}"$.



CLASS S:

Made for exacting miniature requirements. Used in aircraft where resistance to shock and vibration is needed in a small, light, reliable relay. (For printed circuit applications—see below.) Size: $2\frac{1}{8}" \times 2" \times 1\frac{1}{4}"$.



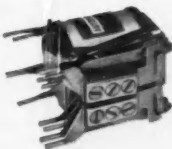
CLASS Z:

Provides maximum timing in a "small-as-possible," low-cost relay. Compact, light, resistant to shock and vibration. Size: $3\frac{1}{4}" \times 2\frac{3}{8}" \times 1\frac{1}{2}"$.



"PLUG-IN" RELAY FOR PRINTED CIRCUITS

Design of coil and spring terminals permits direct insertion into printed circuits with high-conductance connections, easily soldered. Bearing design gives up to 120 million operations without readjustment or relubrication. Size: $1\frac{3}{4}" \times 1\frac{1}{8}" - 1\frac{3}{4}"$ (depending upon number of contact springs) $\times 1"$.



For any application, you can choose an Automatic Electric relay—a top-quality relay in every way—with the additional advantages of *plug mounting*:

Minimized inventory—When you standardize on plug-in relays, you can often interchange the same basic relay in many models of your equipment. Thus, you make substantial savings by reducing your inventory costs, speeding assembly.

Fast, simplified inspection and maintenance—Plug-in relays permit periodic bench inspections with almost no "down time" involved. Entire banks of relays can be removed for testing, and then replaced, in *seconds*.

Simplified replacement—Plug-mounted relays can be replaced quickly and easily at otherwise inaccessible points in your equipment. Even an unskilled service man can replace relays in a matter of seconds without tampering with circuit wiring.

You can select Automatic Electric plug-in relays from five basic types and thousands of individual assemblies.

Send for Relay Circulars 1800—1804—They give complete specifications, dimensional drawings, and helpful information. Address Automatic Electric Sales Corporation, 1033 West Van Buren Street, (Haymarket 1-4300) Chicago 7, Illinois. In Canada: Automatic Electric Sales (Canada) Ltd., Toronto. Offices in principal cities.

AUTOMATIC ELECTRIC

Originators of the dial telephone • Pioneers in automatic control



CHECK YOUR NEEDS FOR DIGITAL EQUIPMENT

The following are typical of components and systems available from Potter for satisfying your digital requirements:

*Digital
Data-Handling
Equipment*

- ☐ Digital Magnetic Tape Handlers
- ☐ High-Speed Perforated Tape Readers
- ☐ Digital "Teledeltos" Recorders
- ☐ Line-at-a-Time Printers
- ☐ Record-Playback Amplifiers
- ☐ Record-Playback Head Assemblies
- ☐ Magnistors
- ☐ Magnetic Core Memory Systems
- ☐ Magnistor Storage Arrays
- ☐ Translation Systems
- ☐ Random Access Memory
- ☐ Magnetic Shift Registers

*High-Speed
Counters,
Timers,
Controllers*

- ☐ General Purpose Interval Timers
- ☐ Preset Interval and Delay Generators
- ☐ Predetermined Electronic Counters
- ☐ Counter Chronographs
- ☐ Frequency-Time Counters
- ☐ Totalizing Counters and Scales
- ☐ Plug-In Counter Decades
- ☐ Photoelectric Count Detectors
- ☐ Photoelectric Screen Detectors
- ☐ Translators and Printers

*Special
Systems*

- ☐ Multiple-Channel Recording Systems
- ☐ Doppler Data Translators
- ☐ Militarized Counters and Timers
- ☐ High-Speed Printing Chronographs
- ☐ Other Data-Processing Systems

You can buy Potter with complete assurance of reliability. As specialists in digital data-handling equipment, Potter engineers welcome an opportunity to study your requirements and to make recommendations for solving your data-handling problems.

Write for detailed technical literature on the above products and other digital equipment available from Potter. Your inquiry will receive prompt attention.

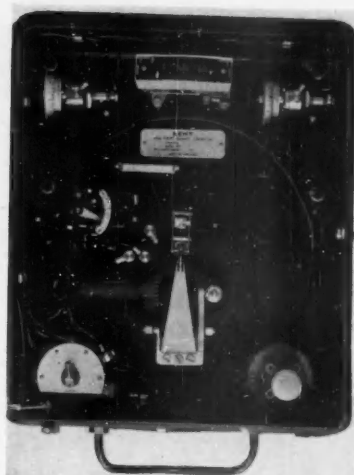


POTTER INSTRUMENT COMPANY, INC.

115 Cutter Mill Road

Great Neck, L. I., N. Y.

NEW PRODUCTS

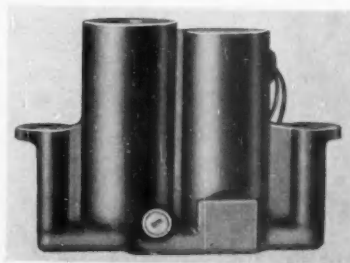


SLACK DIAPHRAGM

This is one of seven new slack-diaphragm-operated pressure controllers. All are of the nonindicating, nonrecording, blind-setting type. Special-purpose units include a furnace-pressure controller, a mill controller, a differential pressure controller, and an air-flow controller. Units permit the conventional modes of control with a 3-to-15-psi output. Supply and control air pressure are indicated on an edgewise gage as percentages of the maximum.—George Kent, Ltd., Luton, Bedfordshire, England.

Circle No. 35 on reply card

POWER SUPPLIES



POWER PACKAGE

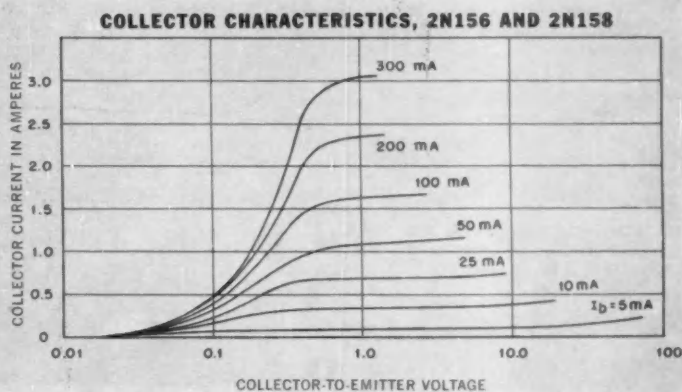
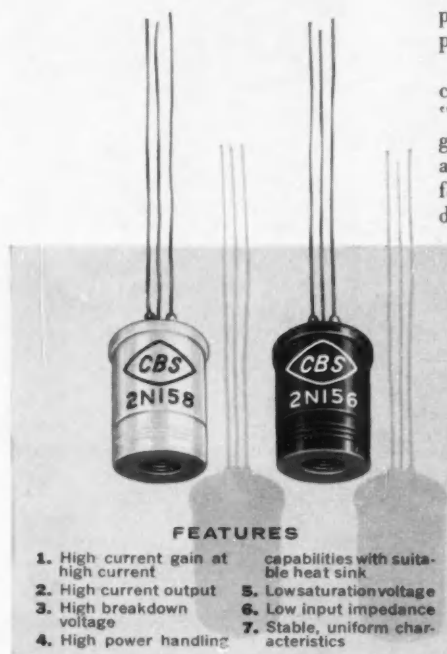
Shown is an electric-motor-driven hydraulic power package for use in guided missiles and supersonic aircraft. The integral casting houses an electric motor, an hydraulic pump, valves, and a reservoir. Powerful, compact, and lightweight, the unit is said

for servo amplifiers
 ... low-speed switches
 ... control circuits
 ... power converters

CBS POWER TRANSISTORS

Just as CBS power transistors have earned a fine reputation in "hybrid" auto radio applications, the CBS 2N156 and 2N158 PNP junction power transistors are recognized as "best on the market" for servo amplifiers . . . as well as many switching, control, and power conversion applications.

Check the advanced-engineering features . . . typical characteristics . . . and graph showing the low collector "ON" saturation voltages. They help to explain the growing popularity of these transistors. Important also are two simple facts: The CBS 2N156 and 2N158 uniformly meet their specifications . . . and they are being delivered in production quantities.



Let our application engineers help you adapt these dependable power transistors to your needs. Write for Bulletin E-259 giving complete data.

TYPICAL CHARACTERISTICS

CHARACTERISTIC	2N156	2N158	
System voltage	12	28	volts
Collector dissipation	5	5	watts
Collector peak inverse voltage	-40	-80	volts
Maximum junction temperature	85°	85°	C
Switching power	26	54	watts
Current amplification ($I_c = 2$ amp.)	20	13	

Reliable products
 through Advanced-Engineering



semiconductors

CBS-HYTRON

Semiconductor Operations, Lowell, Massachusetts
 A Division of Columbia Broadcasting System, Inc.

Kearfott Components

FOR EVERY SYSTEM
APPLICATION



KEARFOTT offers the systems manufacturer the most complete line of precision made components available anywhere. Quantity production enables quick deliveries and reasonable prices.

SYNCHROS—Transmitters, Control Transformers, Resolvers, Repeaters, and Differentials in Bu Ord Sizes 8, 11 and 15. High Accuracy and environmental resistance.

SERVO MOTORS—High torque, low inertia Servo Motors, Inertial and Viscous damped Servo Motors, in Bu Ord Sizes 8, 11, 15, 18 and 23.

TACHOMETER GENERATORS—Available as damping generators, rate generators and integrators. They feature high output to null ratio and extremely linear outputs. Temperature stabilization may be provided.

GYROS—Directional, floated rate integrating, free, vertical, and spring restrained rate gyros for all airborne navigation, stabilization or fire control applications.

Bulletins giving physical and technical data of the various Kearfott Products will be sent on request. The Kearfott organization is available to assist in the development and manufacture of other precision components you may require.



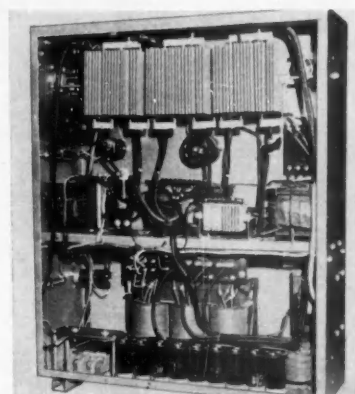
KEARFOTT COMPANY, INC., LITTLE FALLS, N. J.

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NEW PRODUCTS

to permit flexible systems design.—Adel Precision Products, Burbank, Calif.

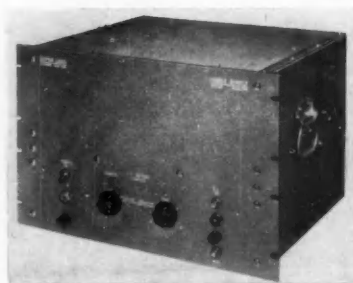
Circle No. 36 on reply card



OVERHEAT PROTECTED

This regulated dc power rectifier uses a three-phase bridge circuit, selenium rectification, and a magnetic amplifier to supply dc computer systems. Convection-cooled selenium rectifier stacks are electrically balanced and fully protected against overheating by a thermal warning switch. Warning is given by a panel light and an audible signal. Other protective features: a positive acting circuit breaker for excessive power input and ample circuit fusing in the output.—Rapid Electric Co., New York City, N. Y.

Circle No. 37 on reply card



FAST RECOVERY TIME

In the range of 0 to 2,500 volts, output voltage variation in this new power supply is less than 0.1 volt for load variations from zero to maximum current and less than 0.2 volt for line fluctuation from 105 to 125 volts. In addition, the recovery time is less

than 50 microseconds. The unit weighs 65 lb and is 12½ in. high, 19 in. wide, and 17 in. deep.—Kepco Laboratories, Flushing, N. Y.

Circle No. 38 on reply card

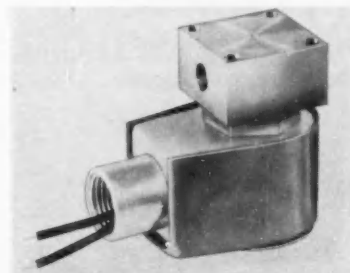


LOW RIPPLE

Designed for use with the manufacturer's own measuring systems, this filtered power supply is said to provide a 1 percent B-plus voltage between 100 and 108 volts dc, and a filament voltage of 6 volts dc with extremely low ripple. Both voltage sources are adjustable and metered so that all equipment can be operated under optimum conditions. The unit operates from 110 volts ac (plus or minus 10 percent), 50 to 400 cps, and is filtered to reduce line transient effects. — Endeveco Corp., Pasadena, Calif.

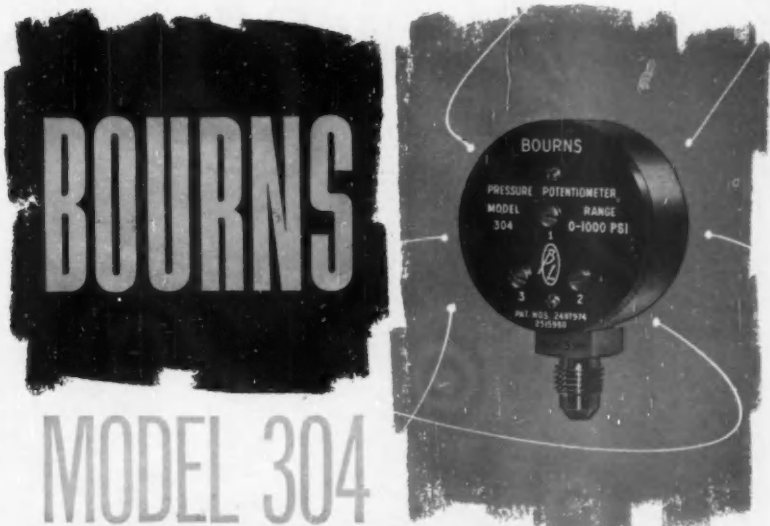
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FINAL CONTROL ELEMENTS



LIQUID CO₂ VALVE

The two-way solenoid valve shown here was designed and developed in response to certain manufacturers' demands for a valve that would automatically control the discharge of liquid CO₂. It is particularly suited for applications where constant tem-



GAGE PRESSURE TRANSDUCER

—high performance in *miniature* size

Only 1½" in diameter...¾" thick, this is an exceptionally small gage pressure potentiometer. Its miniature size and compact configuration permits use in ground and airborne installations—in control telemetering or remote recording circuits—wherever space is at a premium.

Time proved performance. This is a fully integrated instrument built for high reliability under extreme environmental conditions. The dependable Bourns Bourdon tube assembly and linkage system provide exceptional shock, vibration and acceleration characteristics...linearity and hysteresis are excellent. Units are designed to meet or exceed most government specifications for airborne equipment.

The Bourns Model 304 weighs about 2 ounces. It operates with a high-level AC or DC signal. Pressure ranges: from 0-100 to 0-5000 psi. Three Bourdon tube materials are available:

Beryllium copper—the standard construction—for non-corrosive fluids. Measures air, Freon, oil, and other common media.

Stainless steel—permits corrosive fluids such as fuming nitric acid to be applied within the tube.

Ni-Span-C—provides low temperature error for versatility of application.

Complete data in Bulletin No. 304.

ABSOLUTE AND DIFFERENTIAL PRESSURE

In addition to the Model 304, Bourns manufactures a complete line of high pressure transducers in absolute and differential ranges, for use with corrosive or non-corrosive fluids. Request Bulletin No. 70456.



MODEL 704—differential pressure type with stainless steel Bourdon tube



MODEL 706—differential pressure type with Beryllium copper Bourdon tube



MODEL 705—absolute pressure type for use with clean, non-corrosive media

COPR. BL



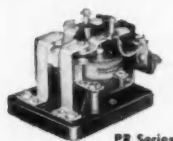
BOURNS LABORATORIES

General Offices: 6135 Magnolia Avenue Riverside, California
Plants: Riverside, California—Ames, Iowa

Potter & Brumfield engineering is in this picture



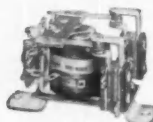
Which P&B relay would you specify to CONTROL AN ELECTRONIC OVEN?



PR Series



MS Series



MR Series

New electronic ovens—the kind that cook an 18-pound turkey to delicious perfection in an hour and a half, and bake potatoes in an amazing 4 minutes—require heavy duty, fast-acting relays designed for high voltage switching. Long, trouble-free service is essential and U/L approval is a must.

P&B's PR 11 relay—easily and economically adapted to this customer's specifications—exactly filled the bill. P&B engineers are old hands at adapting basic relay types to highly specialized uses. Twenty-five busy years of relay designing, engineering and manufacturing at P&B have built an unrivaled backlog of information and skill which is yours to command.

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Potter & Brumfield, inc. PRINCETON, INDIANA
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Manufacturing Divisions also in Franklin, Kentucky and Laconia, New Hampshire



ENGINEERING DATA

SERIES: PR Heavy Duty.

CONTACTS: Max. DPDT. 5/16" dia. silver, 13 amps at 115 V., 60 cycle, non-inductive, 6.5 amps at 230 V., 60 cycle, non-inductive.

VOLTAGE RANGE: 6 to 110 V. DC. 6 to 230 V. AC.

COIL RESISTANCE: 63800 ohm max. DC.

TEMPERATURE RANGE: DC, —45° to 85° C. AC, —45° to 55° C.

PULL-IN: DC, 75% nominal. AC, 78% nominal.

TERMINALS: Heavy duty screw type. Adaptable for printed circuits or plug-in.

BASE: Molded phenolic or metal.

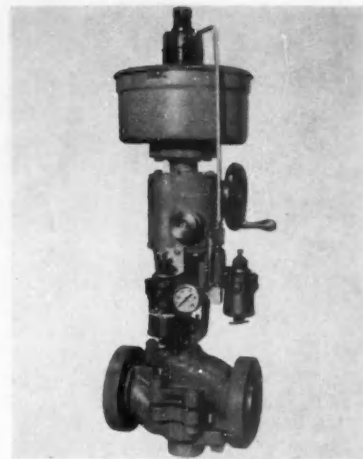
MOUNTING: (2) 3/16" dia. holes on 1 1/8" centers.

DIMENSIONS: 2 1/4" W. x 3 3/4" L. x 2 1/2" H.

NEW PRODUCTS

perature control is essential. Two types of construction are available, one for direct injection, and the other for remote injection. Valve bodies are stainless steel; teflon discs assure tight shut-off on pressures to 1,000 psi.—Automatic Switch Co., Orange, N. J.

Circle No. 40 on reply card



FOR MANUAL OVERRIDE

Available at an integrally mounted accessory for the maker's standard line of pneumatically positioned power actuators, this handwheel operator affords immediate manual control in the event of air failure. It is said to be the only operator of its type that can be instantly thrown in and out of engagement at any position of the stem travel. Clutching and declutching are accomplished simply by pulling or pushing a knob located on the face of the unit. A sturdy aluminum housing prevents dust and grit from clogging the gear assembly.—Conoflo Corp., Philadelphia, Pa.

Circle No. 41 on reply card

CORROSION RESISTANT

A new line of relief valves and back pressure valves is now available for use with corrosive fluids at pressures to 1,500 psi and temperatures to 250 deg F. The top works of these valves are protected by Kel-F thermoplastic diaphragms. Pressure settings are easily changed with a screwdriver. Standard sizes include 1/4, 1/2, 3/4, and 1 in.—Milton Roy Co., Philadelphia, Pa.

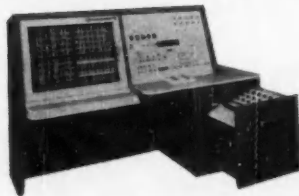
Circle No. 42 on reply card

It's New! It's Revolutionary!

AMP's SHIELDED PATCHCORD PROGRAMMING SYSTEM is especially designed for programming on Analog Computers, Telemetering, Test Equipment, and all types of sensitive low level circuits.

NEW DESIGN FEATURES INCLUDE:

- Fully insulated as well as shielded removable frontboard and fixed rearboard;
- "Post Patching", without shorting as required in Analog Computers and Telemetering;
- Custom Color-Coded circuit legend provided by a cellular type construction that permits individual hole identification;
- Elimination of signal leakage between circuits;
- Shielded Patchcords, with shield terminated by a contact ferrule, which connects to ground when Patchcord tip is inserted.



The illustration shows how Berkeley Division of Beckman Instruments, Inc., is using AMP's new Patchcord System in its new EASE* 1200 Analog Computer.

*Trade Mark, Berkeley Division of Beckman Instruments, Inc.

AMP.

AMP INCORPORATED

Harrisburg, Pennsylvania

Complete information is available
on this New Shielded Patchcord
Programming System on request.

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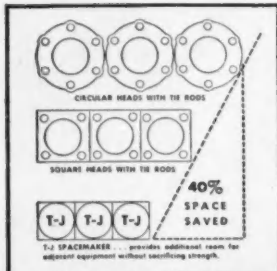


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- Hard Chrome Plated Bodies and Piston Rods (Standard, at no extra cost)
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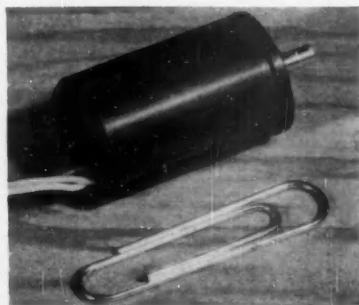
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NEW PRODUCTS



SMALLEST YET

Truly a subminiature unit, this tiny servo motor measures only $\frac{5}{8}$ in. in diam by 1 in. long, and weighs under an ounce. Its extremely small size plus its performance characteristics make it well suited for applications in servomechanisms, computers, missiles, etc. Featuring an unusually high torque-to-inertia ratio, the unit operates on 26 volt, 400 cps power with a control voltage range of 0 to 26 volts. Typical characteristics include: $2\frac{1}{2}$ watt input; $\frac{1}{8}$ watt output; 0.063 in.-oz stall torque; 8800 rpm no-load speed; and 64,000 rad/sec.² theoretical acceleration at stall. Units are available with either smooth or splined shafts.—Ford Instrument Co., Long Island City, N. Y.

Circle No. 43 on reply card



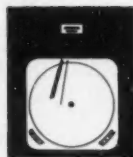
SHAFT-MOUNTED

Shown here is a new shaft-mounted gear motor designed to provide remote and automatic control for variable speed drives, valves, pumps, feeders, and other machines. The motor mounts easily on shafts from $\frac{1}{4}$ to $\frac{3}{8}$ in. in diam. Light and compact in its aluminum housing, the unit is equipped with a torque arm or torque plate to absorb any runout in the

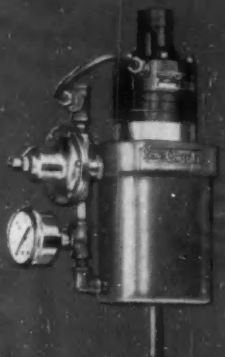
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PROCESSING
EQUIPMENT**



INSTRUMENT



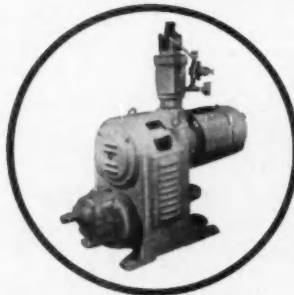
**CYLINDER
CONOMOTOR**

**COST-CUTTING
= AUTOMATION**

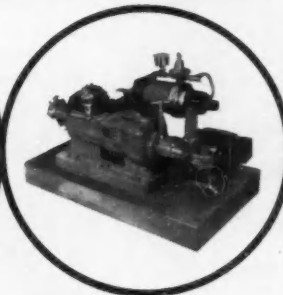
The Conoflow Cylinder Conomotor—a powerful pneumatic actuator—has accelerated industry's approach to the automatic factory and the continuous process plant. A wide range of final control elements, never before available, has been created by the Cylinder Conomotor, a servo capable of following the exact signal outputs of modern electronic and pneumatic instruments.

Cylinder Conomotors, acclaimed by industry as the ultimate in control valve actuators, are fast becoming the standard for automatic control of other process regulating equipment. A few of these are: motor driven speed changers, proportioning pumps, flow regulators, electric timing devices, and numerous electrical systems components such as rheostats, autotransformers and potentiometers.

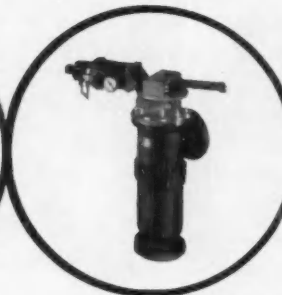
A FEW EXAMPLES OF CONOFLOW AUTOMATION . . .



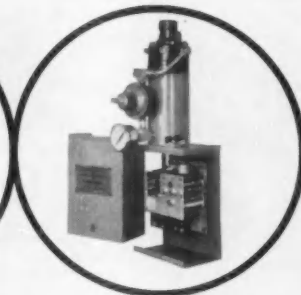
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WRITE FOR BULLETINS B-50-2-A AND EB-2-A

CC-700



CONOFLOW CORPORATION

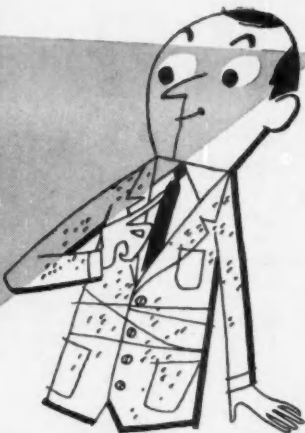
FOREMOST IN FINAL CONTROL ELEMENTS



JANUARY 1957

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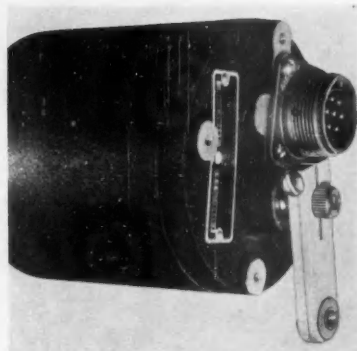
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NEW PRODUCTS

controlled shaft. A wide choice of output speeds and torques is provided by the many reduction gearing ratios that can be furnished. Speeds from $\frac{1}{2}$ rpm to several hundred rpm can be had from the standard units.—The Jordan Co., Milwaukee, Wis.

Circle No. 44 on reply card



SERVO ACTUATOR

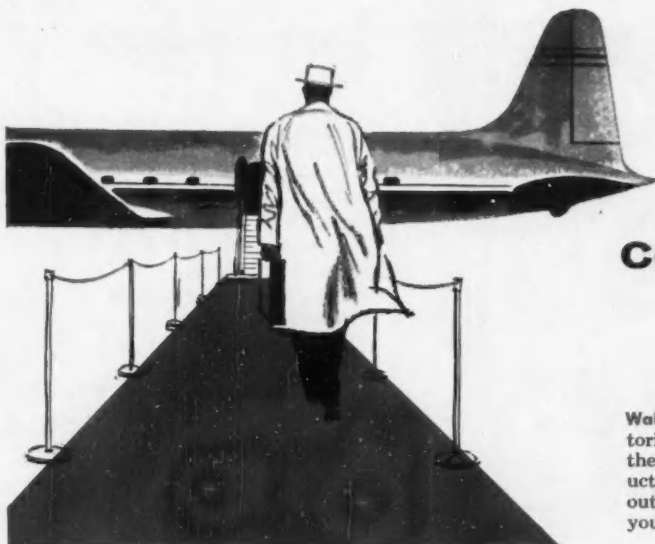
A permanent magnet type rotary servo actuator has been designed specifically for airborne applications. The unit will operate continuously at an output rating of 70 in.-lb at 8.5 rpm. Theoretical acceleration at stall is 40,000 rad per sec, and dynamic braking is incorporated. Unit weighs only 1.9 lb, has a $3\frac{1}{8}$ in. diam and a $4\frac{1}{8}$ in. overall length including the AN connector.—White-Rodgers Co., St. Louis, Mo.

Circle No. 45 on reply card



INDEPENDENT CONTROLS

Maker claims that the solenoid valve shown above is the first to have independent controls for flow adjustment,



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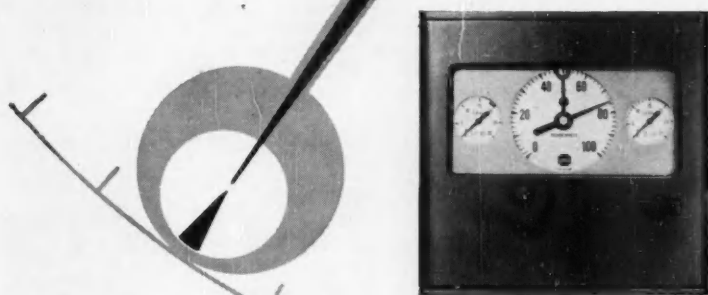
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**shows set point
and process variable**

at a glance!

No other Pilot gives you all the features available in the USG Temperature or Pressure Pilot.

This is an *Indicating Pilot*, with set point and process variable point on the same dial. It also offers:

- Standard proportional band of 1-100% . . . also available to 150%.
 - Band is quickly adjustable.
 - Self-contained all-metal relay (1 1/4 cfm), easily field adjusted.
 - Readily accessible manual reset.
 - Compact (8 9/16" sq. x 4" deep) for ease in panel or field mounting.
- In operation, the USG Pilot provides a pneumatic feed-back circuit with sensitivity of 1/10% and repeatability of 1/2%. Available in a variety of temperature ranges, pressure ranges from 0-30" H₂O to 0-10,000 psi, and in vacuum ranges of 0-30" Hg., with standard control action either proportional 1 to 100% or differential gap. Automatic reset with proportional (1 to 150%) optional.

For complete data on USG Pressure Pilot write your valve supplier today. USG's creative engineering has developed a line of process control instruments that includes temperature and pressure recorders and controllers, pneumatic transmitters and receiver gauges. Write for descriptive catalogs.

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Division of American Machine and Metals, Inc.
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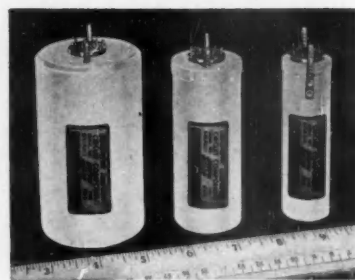
Home of the **SUPERGAUGE**

NEW PRODUCTS

opening speed, and closing speed, and the first with a manual opening stem. The new valve unit can be mounted on piping running at any angle. It is available in all standard sizes from 1/2 in. to 2 in. and its present maximum capacity is 300 psi. Other features include packless design, unbreakable piston rings, full ports, and nonshock closing.—J. D. Gould Co., Indianapolis, Ind.

Circle No. 46 on reply card

COMPONENT PARTS



CIRCUIT COMPONENTS

A new line of magnetic amplifier circuit components can be used as building blocks to assemble any of the well-known basic circuits for fast response and high gain. Units are available with up to 300 watts capacity. Three basic sizes cover the range of 1.5 to 300 watts, 60 cps and 400 cps. The largest unit, rated at 300 watts at 400 cps, measures only 4 1/8 in. in height by 2 3/8 in. in diam. Other units for lower capacity are proportionately smaller.—Adler Electronics, Inc., New Rochelle, N. Y.

Circle No. 47 on reply card

ELECTROLYTICS

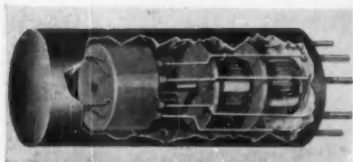
A new line of high-capacitance electrolytic capacitors, designed for filtering power supplies in digital computers and other applications, is now on the market. Design of the new units has, to a great extent, been developed from the telephone quality capacitors which the manufacturer has produced for more than 20 years. Ratings range from 3,600 microfarads at 5 volts to 700 microfarads at 350 volts dc. —Sprague Electric Co., North Adams, Mass.

Circle No. 48 on reply card

TWIN TRIODE

Designed for dc amplifier and computer applications, a new subminiature twin triode features unusually low microphonics and grid current and control of stability with time, shock, and variations in heater voltage, for balance between the two sections.—Raytheon Mfg. Co., Newton, Mass.

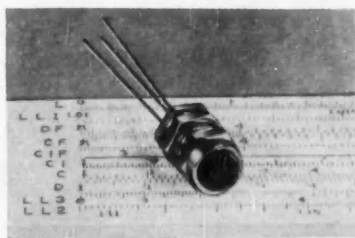
Circle No. 49 on reply card



SHIFT REGISTER

Designated the DATAKOR DK107, this high-speed magnetic shift register uses two cores per bit. The unit is built for reliable operation at speeds up to 500 kc with maximum digit repetition rate above a megacycle. As shown above, all components including the two cores and four gold-bonded germanium diodes are mounted on a miniature tube base and encapsulated in epoxy. Units can also be provided with solder lug headers if permanent wiring is preferred.—Airtronics, Inc., Washington, D. C.

Circle No. 50 on reply card



POT IN A BUSHING

Essentially a locking bushing with a potentiometer built inside, this tiny unit mounts in a $\frac{1}{8}$ -in. hole and measures approximately $\frac{1}{8}$ in. long. The potentiometers, completely housed by the stainless steel bushing, is available in 16 standard resistance values from 47 to 15,000 ohms. All values are manufactured with 20-ppm resistance wire. Power dissipation is $\frac{1}{4}$ watt up to 95 deg C (derated to zero at 145 deg C) for a period of 2,000 hours. Weight of only 2.8 grams suits the units for airborne equipment, while ease of gasketing the mounting surfaces suits them for equipment requiring hermetic sealing.—Carter Mfg. Corp., Hudson, Mass.

Circle No. 51 on reply card

HAGEN Synchronous motors



most powerful for its size

Laminated rotor construction of the Model 50 Hagen Motor produces exceptionally high torque. For example, the rotor develops 10 ounce inches torque at 4 RPM. This motor is ideal for those applications requiring from 5 to 10 times the power of clock-type miniature motors. Yet in spite of its power, the motor is extremely compact:

DIMENSIONS

	50 to 60 cycle	25 cycle
A	3-3/32	3-1/16
B	1-13/32	1-23/32

Just a few of the many possibilities for use are: door chimes, laundry timers, depth finders, animated displays, heating controls, program clocks, fire alarm systems, integrators, time switches, chart drives, scoreboards, potentiometer drives. Motor may be mounted in any position. Wide selection of output speeds from 1800 to 1/6th RPM. Reversible and other models available. Send coupon for Bulletin No. 1055.

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Dept. CE-157, Moline, Illinois

Please send Bulletin 1055 on Hagen Synchronous Motors.

NAME AND TITLE

COMPANY

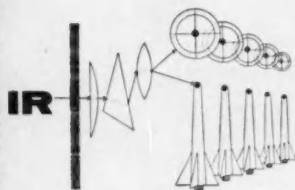
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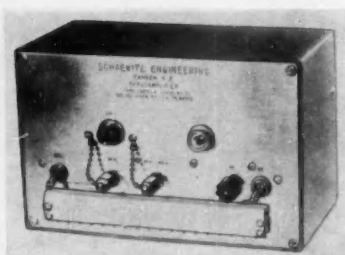
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Perform electronic simulation of control systems using analog computers—analysis and synthesis.



Write: Director of Scientific and Engineering Personnel, Box 296TT, Azusa, Calif. or Box 1947TT, Sacramento, Calif.

NEW PRODUCTS

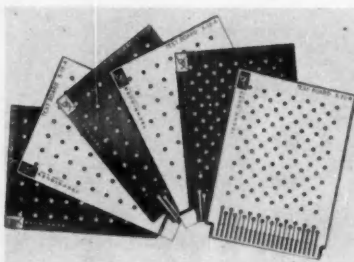


SERVOAMPLIFIER

Called the SA60C-4, this servoamplifier is suitable for applications in which the amplification of minute 60- or 400-cps signals is required to produce up to 4 watts of controllable power. When operated in response to the core displacement of a linear variable differential transformer, an almost unlimited variety of applications is possible. The unit has a power consumption of 30 watts and operates on 105 to 130 volts, 60 or 400 cps. It has a maximum carrier output of 4 watts; 90 microvolts is the minimum input for full output power.—Schaevitz Engineering, Camden, N. J.

Circle No. 52 on reply card

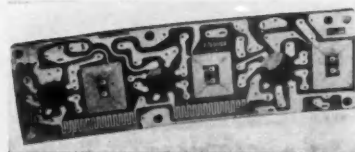
ACCESSORIES & MATERIALS



FOR PROTOTYPE TESTS

These test boards represent a new approach in breadboarding techniques for designing electric circuitry. A full-size work sheet is packaged with each test board for laying out the desired circuit. Patterns soon to be released include a double-sided, matrix-type board for diode and resistor networks. Logic elements, operational amplifiers, flip-flops and other gating and timing circuits are easily designed and installed on these boards.—Techniques, Inc., Hackensack, N. J.

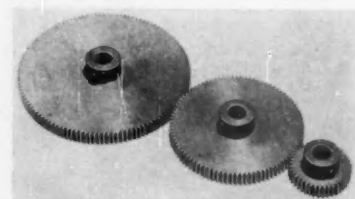
Circle No. 53 on reply card



FOR PRINTED CIRCUITS

Punching clean and sharp at room temperature, this new paperbase phenolic laminate eliminates the need for shrinkage allowances and heating equipment. It is especially recommended for copper-clad laminates used in printed circuitry. The material features high insulation resistance and low dielectric loss at high frequencies. Semi-gloss or dull finish is available.—Synthane Corp., Oaks, Pa.

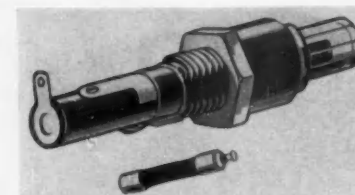
Circle No. 54 on reply card



LINEN PHENOLIC GEARS

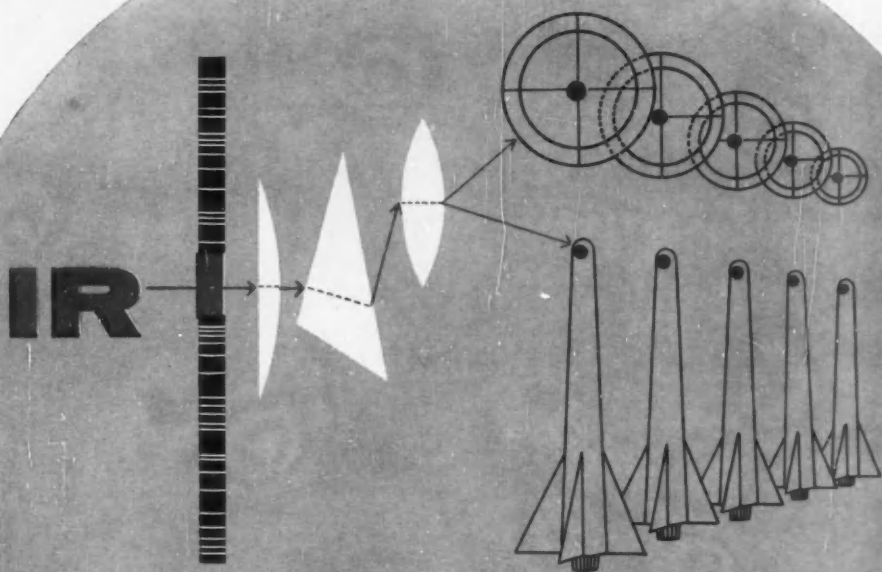
These precision phenolic spur gears are now available from stock in a variety of sizes: 48, 64, 72, and 96 pitch; bore diameters of $\frac{1}{8}$, $\frac{3}{16}$, and $\frac{1}{4}$ in.; and face widths of $\frac{1}{8}$ and $\frac{3}{16}$ in. Gears are cut and stocked to AGMA standards. The material, which conforms to MIL-P-15035, type FBL, is also finished with a fungus-proof varnish before gear cutting.—Pic Design Corp., Lynbrook, N. Y.

Circle No. 55 on reply card



FUSEHOLDER

Panel mounted, this little device combines a fuseholder with an indicating fuse. An indicating pin in the fuse itself is designed to pop out when the fuse is blown, and flash a light, ring a bell, trip a relay, or give some other signal to indicate when or where the trouble has occurred. Possible applications include testing equipment, control circuits, control panels, switchboards, and calculating or computing



INFRA-RED

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For 13 years Aerojet-General has pioneered the research and development of infra-red devices.

Now, Aerojet and Aerojet alone has perfected the high-volume production of infra-red systems for:

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Automatic Control Systems

for tomorrow's needs and hypersonic speeds

Ten years ago—when AUTONETICS began its work—miles-per-hour thinking had to be abandoned. The task of developing guidance and control systems for the Air Force SM-64 NAVAHO Intercontinental Missile demanded engineers who could design, manufacture, test and *produce in quantity* automatic controls that would operate in environments and at speeds never before experienced.

Today—because of its proved ability to convert ideas into engineering fact—AUTONETICS is one of the few organizations in the world with a unique stockpile of experience in information processing, inertial navigation, flight controls, armament control systems, computers and other automatic control systems.

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The projects we are pursuing at AUTONETICS call for extremes in mindpower and environmental facilities.

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And we have a Flight Test Section second to none.

The mindpower—frankly, we'd like to find more of it.

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you have knowledge, enthusiasm and imagination—tempered with judgment. You're both research and production-minded—a dreamer and a doer at the same time. At every level of experience, you'll have an opportunity to conceive and activate an idea. Then prove it—a better way!

And you'll do it in a management climate that stimulates personal growth—and rewards it with the responsibility, professional recognition and material benefits limited only by your own ability. Your own academic stature can be constantly enlarged by our Educational Refund Plan... and some of the nation's finest universities are nearby.

Write today for full particulars. If you're the man we're seeking we'll be glad to arrange a personal interview where you are now residing.

Write: Mr. A. Brunetti, Autonetics Engineering Personnel, Dept. 911, Con, Box AN, Bellflower, California.

ADVANCEMENT IS RAPID WHERE GROWTH IS RAPID



Chief Engineer Robert Ashby, 44, is one of our nation's top electronics scientists. He holds AB and MA degrees in Physics from Brigham Young, a Ph.D. in Physics from the University of Wisconsin. His hobbies are Southern California year-round "naturals"—golf and swimming.



Lester Kilpatrick received his BSEE from Texas Tech in 1946, his MSEE from M.I.T. two years later. During 8 years at North American, he has earned a national reputation as an authority on digital computers. With his wife and 4 year old son, he likes to spend week ends "at the beach."



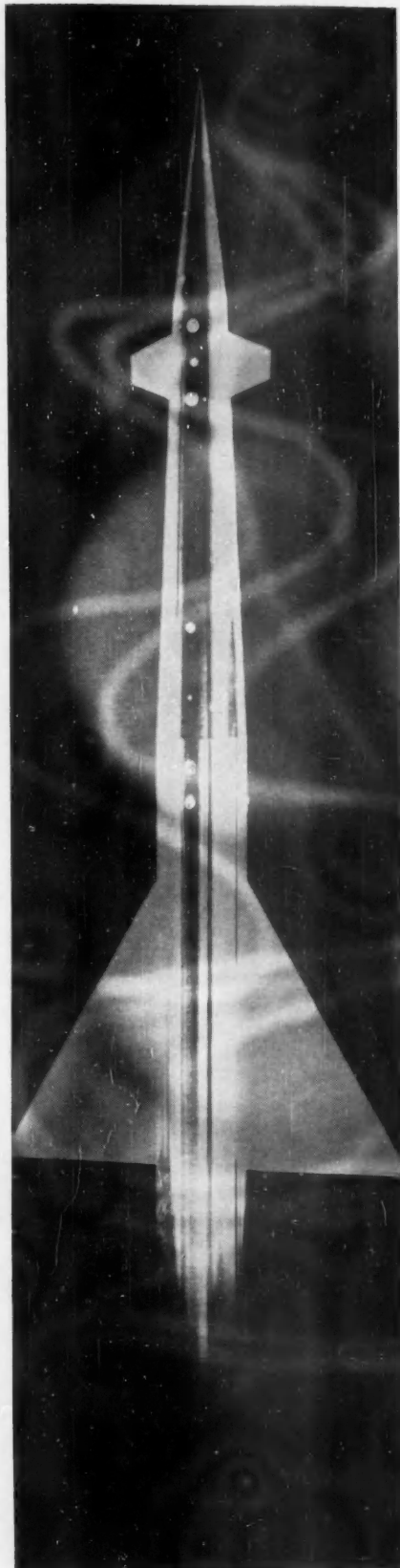
Navy vet E. A. O'Hern joined Autonetics in 1951 after earning his BS, MS and Ph.D. from Purdue University. A Research Supervisor, he has developed advanced techniques for analysis of autopilot-controlled flexible airborne vehicles. His hobbies include baseball, basketball and music.

Autonetics

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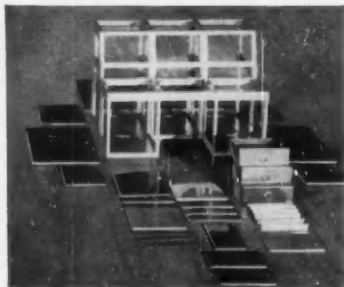
AUTOMATIC CONTROLS MAN HAS NEVER BUILT BEFORE



NEW PRODUCTS

machines.—Bussmann Mfg. Co., St. Louis, Mo.

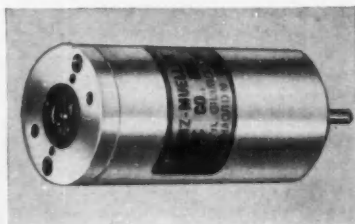
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"ERECTOR SET" CABINETS

Working with 75 mass-produced cabinet enclosures and 125 different sub-parts, a designer can now come up with just the right enclosure for his equipment, at a fraction of the cost of custom cabinets. Airplane-type construction is used in the skeleton frames. Panel-mounting holes are punched automatically in long sections so that the entire interior of the frames is ready to take an endless variety of skins. Forty different types of panels and four different size drawers, ranging from 7 to 14 in. high, and 16 in. deep, make up the component parts which can be fastened to the frames. Writing desk tops, sloping front consoles, extended arm cabinets, and turret panels can be provided, as well as units for television monitoring.—Elgin Metalformers Corp., Elgin, Ill.

Circle No. 57 on reply card



MOTORS AND GENERATORS

A new line of miniature dc motors and generators is now available. Standard units measure 0.875 in. in diam by 1.625 in. long. The shaft diameter is only 0.098 in. Self-aligning sleeve bearings with a nylon retainer assure quiet running. Another important feature is the built-in adjust-

A new name for a proven instrument line...



DESIGNERS, developers and manufacturers of electro-mechanical instruments, *Humphrey Inc.* pioneered this vital field 10 years ago and has maintained its leadership role ever since, distributing on a license basis.

Now, expanded production facilities and expanded markets make it imperative for *Humphrey Inc.* to market its full line of instruments direct... under its own company name.

Better service...increased product line...continued research and development leadership...these will be the direct benefits to customers. The same high quality and performance standards for which these fine instruments have become recognized now will be available under the *Humphrey Inc.* label.



ACCELEROMETERS

Simple, rugged design. No pivots, bearings or loose springs. Pressure-sealed cases; potentiometer pickoffs.



RATE GYROS

Light, compact, rugged. Good producibility, high natural frequency. Exclusive wheel and gimbal system.



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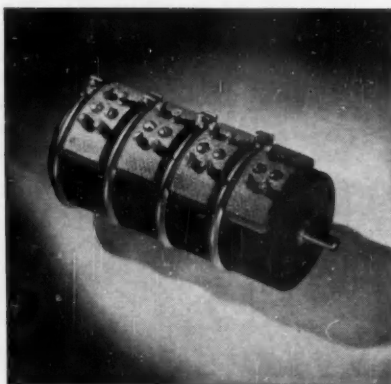
Nonlinear precision wire-wound potentiometers in standard and subminiature sizes are now available in prototype or production quantities from Ace Electronics Associates . . . and you can be sure of delivery.

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able brush bracket that permits accurate speed or voltage output for clockwise or counter-clockwise rotation—Heinz Mueller Engineering Co., Chicago, Ill.

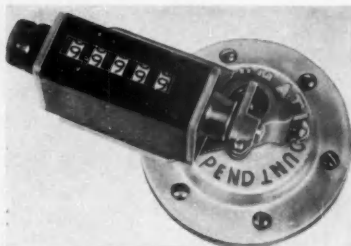
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SPACE SAVER

A new, smaller, single-phase four-pole variable frequency blower motor uses two small external capacitors to achieve fairly constant speed over a wide frequency range. With a 2-in. blade fan, and frequencies between 400 and 1,800 cps, speed is between 7,800 and 11,000 rpm; with a 3-in. fan and 300-1,000-cps frequencies, speed is between 4,400 and 5,200 rpm. Excitation is 115 vac, continuous duty, and ambient temperature range is minus 54 to plus 70 deg C.—John Oster Mfg. Co., Avionic Div., Racine, Wis.

Circle No. 59 on reply card



UP TO 300 COUNTS PER MIN

The automatic counting device shown here is designed to count cycles of any operation controlled by pneumatic or hydraulic action. The unit screws into the line controlling any air or hydraulic cylinder, and is completely installed within 5 min. There are no linkages to assemble and no solenoid, and the maker says there is no danger of half or miscounts. Models are available for from 1 to 5,000 psi, and up to 300 counts per minute. All models are available with either five or six digits, and knob or key reset.—Pneumaticcount, Portland, Ore.

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136	137	138	139	140	141	142	143	144
145	146	147	148	149	150	151	152	153

(100) FLEXIBLE COUPLINGS. Morse Chain Co. Catalog C41-56, 24 pp. Describes torsionally flexible couplings and the principles underlying their design. Complete dimensions and specifications are given on standard, double, and radial couplings. Torsional deflection charts and instructions explain the method of selecting coupling for vibration control.

(101) SILICON RECTIFIERS. Transatron Electronic Corp. Brochure on high temperature silicon rectifiers contains nine specification and rating sheets, and two 4-page bulletins titled "Applications Notes". Spec sheets cover miniature, special, and general purpose types. Notes cover the thermal design problems and surge current ratings.

(102) CORROSION RESISTANT MOTORS. Robbins & Myers, Inc. Bulletin 520, 8 pp. Explains construction features of this company's Series 254-U All-Weather Re-Rated electric motors. A specially treated corrosion-resistant steel housing and a unique design for end-to-end ventilation are a few of the new features.

(103) DC AMPLIFIER. Hilger & Watts, Ltd. Bulletin CH374, 4 pp. Lists operational characteristics and describes the

principle of operation of a new dc amplifier. Made in England, the instrument is distributed in the United States by the Jarrell-Ash Co.

(104) RECTIFIER NOTES. General Electric Co. Brochure, 12 pp. Contains application data on 4JA60 high-current silicon rectifiers. Gives helpful suggestions for obtaining maximum thermal efficiency, and should prove useful to electronic and control equipment designers.

(105) THERMOCOUPLE ACCESSORIES. Minneapolis-Honeywell Regulator Co. Specification sheet S-005-1, 4 pp. Describes the company's line of Quik-Konnect components and other thermocouple accessories. Cable clamps, aluminum disc inserts, tube adapters, and multipoint jack-panels are some of the parts covered.

(106) SANITARY PUMPS. Milton Roy Co. Bulletin 1056, 4 pp. & Data Sheet B-56-1. Bulletin covers general description of a sanitary controlled volume pump for metering liquids with an accuracy of 99 percent. Detailed specifications are given and interesting construction features pointed out. Data sheet describes a typical application in the brewing industry.

(107) "MEN AND MACHINES". Servo

Corp. of America. This 4-page brochure lists all the production facilities maintained by Servo Corp. These include machine tools and laboratory and testing equipment. Should be interesting to engineers placing sub-contract work.

(108) FLUID DRIVES. American Blower Corp. Bulletin A-119. Discusses advantages and applications of adjustable speed Gyrol fluid drives. A description of construction features accompanies an example of how the unit operates. A cutaway view of a typical unit is included.

(109) HEATER CONTROLS. Fenwal, Inc. Brochure, 4 pp. Eight different configurations of aircraft heater controls and a rate-of-rise control are pictured, along with dimensional and electrical specifications. Describes the operating principle involved and cites several typical applications.

(110) CAP CONNECTORS. Alden Products Co. Handbook insert, 18 pp. Contains complete descriptions of tube cap connectors for every type of electronic tube. Connectors are classified by cap size and then grouped by types. Handy charts make it possible to select the best insulation for each application.

(111) JET VACUUM PUMPS. Schutte

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& Koerting Co. Bulletin 5H3, 8 pp. Third in a series, this bulletin describes the company's three-, four-, and five-stage steam jet vacuum pumps and vacuum boosters. Illustrates both condensing and noncondensing types, and covers materials of construction, operation, and application.

(112) "PIC FROM STOCK". PIC Design Corp. Catalog 11, 128 pp. Lists over 4,000 precision instrument and servo parts available from stock. A number of development kits also described. Data sheets in back cover military specs, ways to measure torque, and some typical component assemblies.

(113) LEVER SWITCHES. International Instruments, Inc. Engineering Data Sheet describes two new sub-miniature lever switches. Sheet includes all electrical characteristics, details of construction, listings of available models, specifications, and mounting dimensions.

(114) PROPORTIONING PUMP. Proportioners, Inc. Bulletin 1140. Numerous photos, capacity charts, and dimension drawings point out the design features of a new chemical proportioning pump. Text covers accuracy, positive feed rate setting, and possible applications.

(115) OVERHEAT DETECTORS. Fenwal, Inc. Brochure MC-134, 4 pp. Describes a new series of thermistor-actuated overheat detectors, and points out the advantages of sensing temperature with thermistor elements. Brochure suggests applications and installation techniques, and lists specifications.

(116) MOTOR OPERATED VALVE. Hydromatics, Inc. Technical Bulletin 23, 2 pp. Provides detailed description of a unique valve design that gives zero pressure drop and zero leakage under extreme temperature and environmental conditions. Also includes dimensions and operating specifications.

(117) "DATA FOR DECISION". Logistics Research, Inc. Brochure gives a detailed description of the new ALWAC 800 data processing system for business, industrial, and scientific applications. Shows how all functions (calculation plus input and output) can be simultaneous.

(118) MOTOR PROTECTION. Allis-Chalmers Mfg. Co. Leaflet O5 R 8525, 4 pp. Describes an integrated salient pole field coil with a newly developed insulating system designed to protect electric motors and generators from atmospheric

contaminants and destructive mechanical forces.

(119) CALCULATING BOARD. Jarrell-Ash Co. Bulletin SCB 1056, 2 pp. Contains information on a new calculating board designed to save time in constructing spectrographic calibration curves. Board transforms curves into nearly straight lines by means of log-log scales.

(120) THERMISTOR SELECTION. General Electric Co. One-page table contains multipliers for selecting thermistors as temperature compensators. Table is reduced to a per unit basis and applies to grade 2 thermistors. Indicates directly the maximum deviation from average of any selected temperature range, and permits quick component selection.

(121) MOISTURE CONTROL. Beckman Instruments, Inc. Two-page technical data sheet outlines an improved method of moisture control in natural gas streams. Shows how the company's Electrolytic Hygrometer removes the uncertainties from the drying cycle, thereby improving the efficiency of the system.

(122) SCIENTIFIC COMPUTER. Remington Rand Liv., Sperry Rand Corp. Nine-page operational guide describes the new Univac Scientific 1103A electronic computing system. Letter-sized, the booklet includes a 3-page section on terminology, including definitions of word length, instruction word, address locations, arithmetic registers, control registers, etc.

(123) TELESYN SYNCHROS. Ford Instrument Co. Brochure, 12 pp. Illustrates this firm's standard line of size 1-, 3-, and 5- Telesyn synchros. Provides application information, detailed specifications, and performance data on these same sizes.

(124) SWIVEL JOINTS. Barco Mfg. Co. Bulletin 269-A, 12 pp. Explains in detail two new types of swivel joints for use in aircraft. Illustrations of all standard patterns are shown with specifications for flared and flareless connections in aluminum, steel, and stainless steel. Applications of standard and special joints in many types of flexible assemblies given.

(125) TEST EQUIPMENT. Allen B. DuMont Laboratories, Inc. "DuMont Catalog of Components and Accessories" lists the company's complete line of accessories for electronic test equipment and components for electronic circuitry. Photographs, written descriptions, catalog numbers, prices for each item included.

(126) STAINLESS FASTENERS. All-metal Screw Products Co., Inc. Condensed stock list, 8 pp. Thirty-seven different basic fastening devices illustrated and described in this new brochure. Data cover threads, head and point styles, and grades of stainless steel used.

(127) PLUG VALVES. Homestead Valve Mfg. Co. Catalog RB 39-5, 28 pp. Illustrates and gives engineering dimensions of a line of lubricated plug valves, shows different types of power operators for valves and a complete line of lever-operated and worm- and gear-operated valves.

(128) PORTABLE TESTERS. Fenwal, Inc. Brochure, 4 pp. Describes four types of portable kits for testing and calibrating all types of thermostats, fire detectors, and heater controls made by Fenwal. Applications, physical dimensions, electrical rat-

ings, and other pertinent specifications included for each kit.

(129) **CHLORINE GAS FEEDERS.** Builders-Providence, Inc. Bulletin 840-N10, 4 pp. Covers the construction features, operation and application advantages, safety features, and physical dimensions of two visible-flow chlorine gas feeders. Four types of control are diagrammed: manual, semi-automatic, program, and automatic proportional.

(130) **PRIMARY ELEMENTS.** Aero Research Instrument Co. Brochure, Sec 3, 12 pp. Illustrates miniature and standard temperature and pressure sensing instruments, outlines use and specifications for pressure probes, thermocouples, connectors, and terminal fittings.

(131) **SUB-MINIATURE METER.** International Instruments, Inc. Engineering Data Sheet. Provides information on a new 1-in. round, flush-mounting panel meter. Data include specifications, standard ranges, maximum resistances, and important dimensions.

(132) **"RELAYS AND SWITCHES".** Jaidinger Mfg. Co. Catalog, 12 pp. Shows about 40 different switches and relays, ranging in size from standard units to the miniatures, and describes the operation and characteristics of each. Also gives specs, sizes, capacities, etc.

(133) **THICKNESS CONTROL.** Industrial Nucleonics Corp. Bulletin No. B-1556, 12 pp. Titled "AccuRay Strip Thickness Control Systems for the Metalworking Industry", bulletin describes the company's radiation equipment for the measurement and control of thickness and illustrates the accuracy of this equipment in several rolling-mill applications.

(134) **WEIGHING SYSTEMS.** The A. H. Emery Co. Bulletin 561, 12 pp. Describes the "rolling ball" construction of the Emery load cell, covers a number of different arrangements for tank and bin weighing systems. Indicating, recording, and controlling instruments of several manufacturers are pictured.

(135) **MOTOR CONTROLS.** Allen-Bradley Co. A-B Handy Catalog, 132 pp. Contains operational, dimensional, and price data on the company's complete line of manual and automatic motor controls. Conveniently indexed for quick reference, the catalog illustrates almost every type of control and accessory.

(136) **FLUID DRIVES.** American Blower Corp. Bulletin 9119, 16 pp. Describes three types of fluid drives for industrial use in the low horsepower range. Explains the fluid drive principle and outlines its advantages. Compares a direct-connected ac motor with a similar motor using the Gyrol fluid drive.

(137) **"SYNDUCTION" MOTOR.** Allis-Chalmers Mfg. Co. Bulletin 51B8440A, 4 pp. Describes a new synchronous induction motor that makes constant speed drives dependable, simple, and inexpensive. Lists design features, gives examples of constant and adjustable speeds.

(138) **DIAPHRAGM VALVE.** A. W. Cash Co. Bulletin 980, 4 pp. Covers the maker's Type 30 Diaphragm Control Valve. Includes details on the valve's available sizes, specifications and dimensions, pressure and temperature ratings, capacities, optional accessories, etc.

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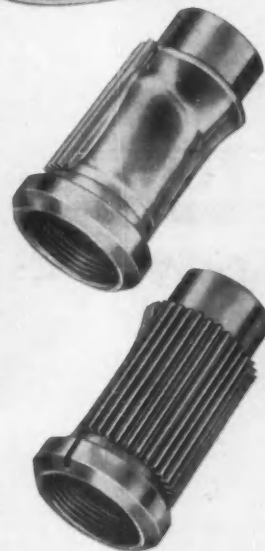
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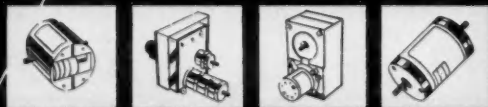
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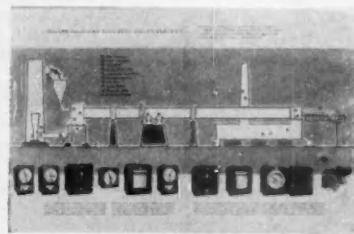
APPLICATION LITERATURE

(144) DATA PROCESSING. International Business Machine Corp. IBM Data Processor, Vol. 1, No. 3 (Sept.-Oct. '56) Published bi-monthly for managers of IBM installations, these papers contain some interesting articles and tips on data processing techniques. In this particular issue, the cover article, shown here, deals



with the application of transistors to commercial calculators. Under the heading of "Application Pointers", a second article shows how the principle of selective reproducing has been applied to market analysis work. On page 7, inside the back cover, are a number of scale drawings showing the shapes and space requirements of the 650-700 series machines. Transparent plastic templates, similar to these drawings, are available at IBM branch offices.

(145) KILN INSTRUMENTATION. Leeds & Northrup Co. Folder N-0720(1) 1956, 14 pp. Titled "Modern Practices in Rotary Kiln Instrumentation", this new folder shows in photographs and diagrams how L&N instruments and controls are used in the manufacture of cement, lime,



and other nonmetallic products. Pictures of on-the-job installations complement the discussions of operating principles. Shown is a spread of pages 3 and 4 that illustrates how instruments and controls are applied to a typical kiln.

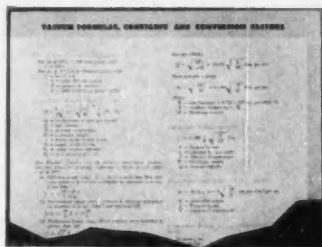
(146) BASIC REACTOR GUIDE. Minneapolis-Honeywell Regulator Co. Booklet, 8 pp. This handy booklet, called "Nuclear Reactors—A Basic Guide", was published for the layman in an effort to dispel some of the fog surrounding reactor terminology. It should also prove interesting to engineers who are unfamiliar with recent developments in the nuclear field. All im-

portant definitions are included in two tables. The first of these, part of which is shown here, covers basic reactor classifications. It gives the name of each class,

TYPE OF REACTOR CLASS	NAME CLASS	CHARACTERISTICS
Fixed Reactor	Basic Reactor	Basic and primary 1/2 power motor (1/2 to 1/40 r.p.m.) for use in control applications. It is designed to operate at 1/2 power and is not to be used as a motor.
Adjustable Reactor	Basic Reactor	Basic and primary 1/2 power motor (1/2 to 1/40 r.p.m.) for use in control applications. It is designed to operate at 1/2 power and is not to be used as a motor.
Regenerative Reactor	Regenerative Reactor	Regenerative Reactor (1/2 to 1/40 r.p.m.) for use in control applications. It is designed to operate at 1/2 power and is not to be used as a motor.
Commutator Reactor	Commutator Reactor	Commutator Reactor (1/2 to 1/40 r.p.m.) for use in control applications. It is designed to operate at 1/2 power and is not to be used as a motor.
Motor-Generator Reactor	Motor-Generator Reactor	Motor-Generator Reactor (1/2 to 1/40 r.p.m.) for use in control applications. It is designed to operate at 1/2 power and is not to be used as a motor.

the origin of the name, and the essential features of each. A second table covers specific reactor types.

(147) MORE VACUUM DATA. F. J. Stokes Corp. Catalog No. 752, 28 pp. In addition to specifications for a complete line of high-vacuum pumps, this revised catalog contains a wealth of other useful



information that should prove helpful to engineers confronted with vacuum processing problems. A section on pump selection gives several typical problems and their solutions. A number of vacuum formulas, constants, and conversion formulas are grouped on a single page, part of which is shown above.

(148) FOR STATIC CONTROL. General Electric Co. Bulletin GEA-6578, 8 pp. "Fundamentals and Features of General-Purpose Static Control Elements" is the title of this recent GE bulletin. It re-



views the logic function concept and its application to conventional control, then goes on to consider the basic principles of static control. Photos include an exploded view of a partial control panel and a well-labeled shot of four logic elements in a panel sub-assembly.

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- guaranteed 20 in. oz. at 1 r.p.h. (1/60 r.p.m.)
- dependable power for automatically operated controls of all types

Here's new slow motion power engineered into the same small Synchron size . . . the new 1 r.p.h. motor. Designed for use in switches, timers, and special control applications . . . eliminates need for extra gears between 1 r.p.m. and 1 r.p.h. in intermittent time trains; provides a gear train with lifetime lubrication, enclosed and trouble-free.

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(Continued from page 44)

computers' abilities in solving research problems. Also preceding the UCLA 705 are installations of 650 magnetic drum processors, at reduced rentals, in 18 other U. S. colleges and universities, pledges to 14 more like institutions, and presentation of a 701 data processor to UC's Berkeley campus.

Behind the installation of the 705 is an expressed need by 1966 for 170,000 professional computer handlers, more, says IBM's Cuthbert C. Hurd, director of data processing machines, than the number of members in the American Medical Association. The UCLA gift, viewed as a major step in alleviating this shortage, will be placed in the hands of business researchers and students from colleges and universities in 11 western states. With the Berkeley computer, which will be used chiefly for scientific problems, the 705 closes the loop, so to speak, on a well-rounded UC program in computer techniques.

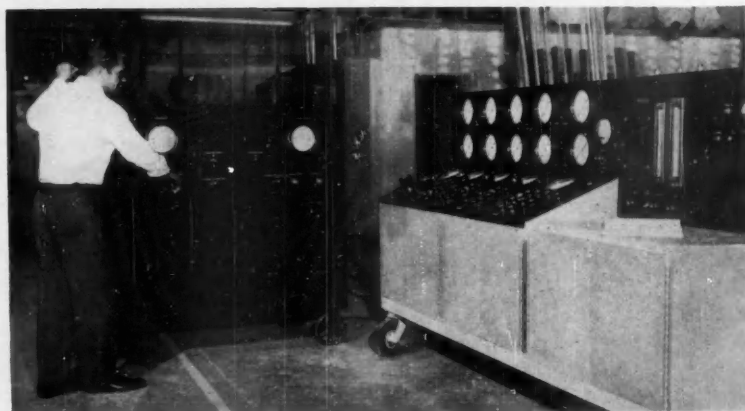
On Nov. 19, a meeting of representatives of many of the educational institutions signifying desire to participate in the new center was held to discuss cooperative use of the 705. High up on the agenda was recognition of the fact that the students must be taught the new techniques, must learn how to apply advanced electronic computing methods to the most complex manufacturing and dis-

tribution problems faced by modern business management. Eyes of all were on Hurd's date, 1966, because by then there will be more than 10,000 digital computers in operation, and the need for trained users will be terrific.

All machines in the center will be installed and maintained by IBM, which will also make a substantial grant to support computer research assistants selected from graduate schools of western colleges and business schools accredited by the National Association of Collegiate Schools of Business. These assistants, coming to the center with degrees in accounting, engineering, mathematics, logic, or the sciences, will teach electronic data processing in their own schools after their period of training. A full-time director for the center, to work with an advisory committee from participating colleges, will be appointed soon, according to Chancellor Raymond B. Allgen.

► **North American Aviation, Inc.**, has established a brand new **Reliability & Standards Dept.** and has elevated other areas of its operations to departmental status. Boosted up are guidance, under S. F. Eyestone; flight control, D. L. Williams; armament control, J. C. Elms; flight test, D. B. Wright, and data processing equipment, G. D. Shere. The new R&S Dept. is composed of the component

Lear's Rocket Test Looks Like It's Done with Mirrors



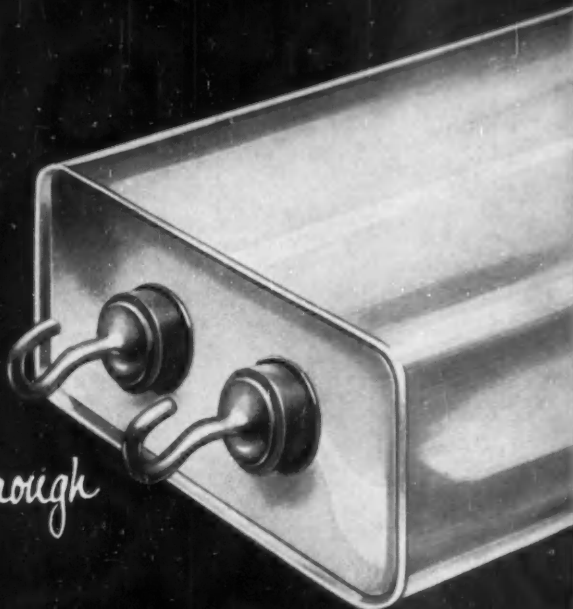
Remember the gadget Monroe developed for checking out the Monrobot VI computer (CtE, Aug. '56, p. 24)? Well, here's something along the same lines, but on a somewhat larger scale. It's a test stand that checks a test stand that tests a rocket engine. On the right in the picture are mobile pneumatic and electrical test stands

built by the Aircraft Engineering Div. of Lear, Inc., for the Rocketdyne Div. of North American Aviation, which wanted a way to check rocket engines without actually firing them. The test stand on the left makes sure that the test stands on the right do the job right. What's that behind the operator? Another. . . ?

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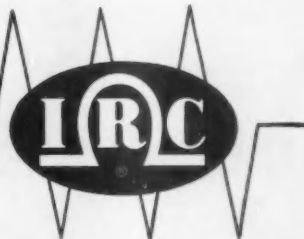
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WHAT'S NEW

evaluation group, the environmental laboratory and the automatic check-out group.

► Westinghouse Electric Corp.'s Transformer Div. at Sharon, Pa., already split into two departments, **Distribution Transformer** and **Specialty Transformer**, has given birth to a third unit, a **Power Transformer Dept.** In charge is R. N. McCollum, formerly division sales manager.

► The largest known dynamic radiation facility in the world, housing a cobalt 60 source, is one of the units being built in Morton Grove, Ill., by **Cook Electric Co.** (CtE, Dec. '56, p. 156). Engineering and design of the facility are in the hands of a new Cook-created company, **The Nucleodyne Corp.**, which will specialize in environmental testing equipment, radiation test facilities, and other projects for firms involved in nuclear applications and space flight research. President of Nucleodyne is Walter C. Hasselhorn, vice-presidents are Jan Romer and Carl Hermanson.

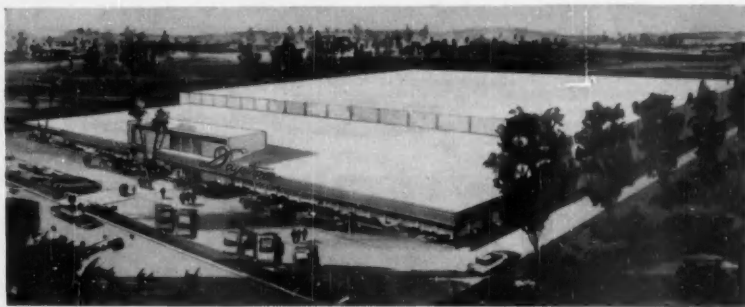
► Another new company, this one organized in San Francisco, is **Granger Associates**, which is being steered by John V. N. Granger, formerly assistant director and head of the **Radio Systems Laboratory of Stanford Research Institute**. Initially the company will limit its work on military and commercial electronic systems to radio and radar. President Granger has an interesting background; it includes teaching fellowships in physics and communications at Harvard, war work in radar in England and France, a research fellowship (again at Harvard) and contributions there to the **Electronics Research Laboratory**. He joined the Stanford institute in 1948 and helped organize its antenna research program. He is a fellow of the IRE.

► In 1953 when James J. Pandapas was an officer and half-owner of **Electro-Tec Corp.** of Hackensack, N. J.,

his company was engaged in the manufacture of miniature slip ring assemblies, brush assemblies, and commutators by a process that it considered to be exclusive. In the middle of that year Pandapas left **Electro-Tec** to organize **Poly-Scientific Corp.** in Blacksburg, Va., and soon afterward his new company began marketing a similar line of components. Two years later, in 1955, **Electro-Tec** and its subsidiary, **Instrument Corp. of America**, filed a suit against Pandapas and **Poly-Scientific**, seeking "to enjoin the use and disclosure of trade secrets claimed by the complainants". Specifically, the suit charged that Pandapas violated a contract between himself and **Electro-Tec**, which prohibited him from manufacturing, by **Electro-Tec's** exclusive process, any product made by his former company. A restraint order was sought. Pandapas, answering the complaint, declared that **Poly-Scientific's** process bore no resemblance to the one used by **Electro-Tec** and that it had been developed in **Poly-Scientific's** own laboratories by its own personnel. Last October, Judge Lyttleton Waddell, sitting in Montgomery County Circuit Court, Virginia, sided with Pandapas and dismissed the complaint against him.

Companies A-Building

► A factory (50,000 sq ft) in Westchester, Calif., near the Los Angeles International Airport, for **Daystrom Pacific Corp.**, one of the newest members of the **Daystrom, Inc.**, family. Also for **Daystrom**: district sales offices in Los Angeles, Philadelphia, and Union, N. J., for its **Weston Electrical Instrument Corp.** subsidiary. **Daystrom Pacific** is an outgrowth of the merger, in 1954, of **American Gyro Corp.** into the parent company. Soon after **Daystrom Pacific** was incorporated, its two divisions were born: **American Gyro** and **Daystrom Potentiometer**.



Daystrom Pacific Corp.'s West Coast factory: a well-earned pat from a proud parent.



G. D. Schott (center), Flight Controls Department head, discusses a rocket control system with Group Engineer R. A. Fay (right) and F. G. Hudson, missile components research specialist.

FLIGHT CONTROLS THEORY

The transition from theory to reliable components is one of the most difficult phases of flight controls endeavor. At Lockheed Missile Systems Division, engineers and scientists are performing advanced work on a number of theoretical approaches that offer important practical solutions.

Two of the areas are:

- Utilization of feed-back design techniques for optimizing complex dynamic systems
- System verification by analog computer simulation

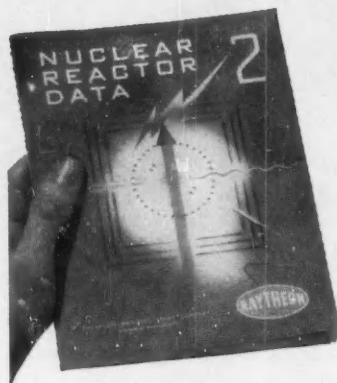
Significant developments in these and related areas have created new positions at both Sunnyvale and Van Nuys engineering centers. The complex nature of the assignments requires both flight controls experience and the ability to exercise individual initiative. Inquiries are invited.

Lockheed **MISSILE SYSTEMS DIVISION**
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WHAT'S NEW

► Offices and research laboratories (60,000 sq ft) in Fairfax County, Virginia, for **Atlantic Research Corp.** The one-story structure to go up at an intersection eight miles from Washington, D. C., will include small-scale laboratories, facilities for acoustic instrument development and manufacture, and offices for technical and administrative personnel, who now total 175. The 43-acre, campus-type quarters are expected to be ready for occupancy by 1958.

► A research laboratory (\$2.5 million) in Los Angeles for **Federal Telecommunication Laboratories Div. of International Telephone & Telegraph Corp.** The three-building center, to be located next to facilities of another IT&T division, **Federal Telephone & Radio Co.**, will house work in digital computers, inertial navigation systems, infrared research, etc. Ten air-tight "clean rooms" with electrostatic precipitators, and a \$20,000 sidereal test stand for gyroscopic research will be among the features. Completion is set for 1960.

► A manufacturing plant (120,000 sq ft) in Fort Washington, Pa., for **Minneapolis-Honeywell's Valve Div.** The \$14-million facility, to house all phases of manufacturing, sales, research, development, and administration, will include a 300-car parking lot and recreation areas. An eventual expansion of the division from its present 300 employees to an anticipated 1,000 has been built into the design of the plant, which will be ready for occupancy about the middle of 1957.

► A second (40,000-sq-ft) section for **ElectroData's** two-story plant in Pasadena. Three similar buildings for the **Burroughs Corp.** division are scheduled for completion by March.

► An electric panel meter facility (10,080 sq ft) near Oceanside, Calif., for **Triplett Electrical Instrument Corp.**, a subsidiary of TEI of Bluffton, Ohio.

► New headquarters (15,000 sq ft) in Svossset, N. Y., for **Fairchild Camera & Instrument Corp.'s Electronics Div.** The leased building, next to two other Fairchild plants, houses research and test equipment, a technical library, several laboratories, dark-rooms, and two design and drafting sections.

► Headquarters in Phoenix, Ariz., for **General Electric's Computer Dept.**, whose key personnel are expected to make the move from Syracuse, N. Y., early next year. First product to be delivered by the department once its relocation is completed is the ERMA

computer system ordered by The Bank of America. Computers designed for other specific business, industrial, and military applications will follow. No plans, says Department General Manager H. R. Oldfield Jr., have been made for manufacturing large-scale, general-purpose machines.

Also for GE: a research laboratory in the San Francisco East Bay area that will design power plants for aircraft and guided missiles. The 75 engineers to be located at the 7,000-sq-ft San Ramon facility will be part of the company's **Flight Propulsion Laboratory Dept.** in Cincinnati, Ohio.

► A warehouse and sales office (16,000 sq ft) in Chicago for **The Powers Regulator Co.** The facility is the tenth office-warehouse to be built or re-modeled by Powers since 1954.

► Among recent acquisitions: **Davies Laboratories, Inc.** of Beltsville, Md. (high-speed data-recording systems) by **Minneapolis-Honeywell Regulator Co.**, which will keep President Gomer L. Davies in charge as general manager; **North American Instruments, Inc.**, of Altadena, Calif. (electronic test equipment, microwave relay links, etc.) by **Philco Corp.**, which will operate Sierra as a wholly-owned subsidiary in the **Government & Industrial Div.** with former president Willard Feldscher as vice-president and general manager; the **Gouvernaire** line of regulators manufactured by **Bellofram Corp.** by the **Stratos Div.** of **Fairchild Engine & Airplane Corp.**, which will add the pneumatic-pressure units to its own line of direct-operated regulators. Concurrently, the Fairchild division expands into a 7,500-sq-ft building in Babylon, N. Y.

Important Moves by Key People

► Jesse Stitzer, the new chief engineer of the Beta Electric Div. of Sorenson & Co., Inc., succeeds Victor Wouk, promoted to general manager and engineering director. Stitzer came to the division in 1950 and for the past three years has been a project engineer in high-voltage dc power supplies. He holds several patents in this field. Wouk's elevation is in line with a recent reorganization and expansion program.

► Ford Instrument Co.'s title of administrative assistant to the vice-president for engineering goes to Joseph A. Despres, a former executive of Airborne Instruments Laboratory, Inc., and inventor of a process for electroforming component parts. At Airborne Instruments Despres was administrative assistant to the director of the Engineering & Production

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Model F3: Ranges of 0-1%, 0-5%, 0-10%, and higher. Meter on door for convenient readings at sampling point.

Model G2: Full scale ranges 0-0.1%, 0-0.5%, and others for low O_2 content. Ranges 90-100%, 95-100% O_2 for high O_2 content.

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STRATOS

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WHAT'S NEW

Div., a post he held for the three years following service with the ECA as industry office in The Hague, Netherlands. Before that Despres was president and chief engineer of Bernard Rice's Sons, Inc. His war work at MIT's Radiation Laboratory resulted in development of the electro-forming process, which later was specified on government and other contracts.

► Two important changes in Emerson Electric Mfg. Co. spotlight **Edwin W. Logan** formerly chief electronics engineer, appointed director of the Dept. of Research, and **Robert E. Kern**, formerly assistant to Logan, succeeding him as chief. Logan's department will work closely with the Electronics & Avionics Div., which is carrying out projects in aiming devices, guided missiles, radar assemblies, servos, computers, rocket launchers, airframe structures, and airborne, land-based, and shipboard instrumentation. Much of this activity has been transferred to a new, one-story building whose 40,000 sq ft will accommodate 500 persons. E&A now accounts for one-third of Emerson's annual sales.

► As director of laboratory operations of IBM, **Robert W. Schubert**, formerly assistant director, will work closely with all research and development laboratories on administrative matters. He joined the company in 1950 at the Watson Laboratory in New York and subsequently became

a member of the senior scientific staff. In this capacity he supervised the administrative phase of the NORC computer development. An assignment as technical specialist in product planning followed, and early in 1956 he was named to the IBM administrative training program.

► Managing Editor **Lloyd Slater** got so caught up in his "other" job of publicity chairman for the ISA that he notified every publication but his own about the new hand at the ISA helm. That's why we're late with the news that **Justus T. Vollbrecht**, president of Energy Control Corp., has succeeded **Robert T. Sheen**, president of the Milton Roy Co., in that very important post. Vollbrecht founded Energy Control of New York in 1938, and in 1941 formed its Baltimore-Philadelphia counterpart. His election as ISA president brings to a close two years of service as national treasurer of the society.

Figuring in another ISA appointment is **George A. Hall Jr.**, former manager of education of the Bristol Co., who joins the staff of the ISA Journal as assistant editor. Hall backs up his talents as a technical writer with solid experience in the field as an instrument and automatic control engineer.

► Chief engineers of two departments in its Semiconductor Products Div. have been appointed by Motorola, Inc. They are **Earl L. Steele**, chief



Jesse Stitzer



J. A. Despres



E. W. Logan



R. W. Schubert



G. A. Hall Jr.



J. T. Vollbrecht

development engineer of the Device Development Dept., and Ben R. Gossick, chief engineer of the Circuitry Dept. Both men will be located at



E. L. Steele



B. R. Gossick

Phoenix, Ariz. Steele is a former research chemist with General Electric Co. Gossick has done research in semiconductors at Purdue University and has worked in electronic instrumentation at Oak Ridge and RCA.

► **Harry O. Wolcott**, formerly general manager of Electromec, Inc., has been named chief engineer and production manager of the Instrument Div. of Federal Telephone & Radio Co., a division of IT&T. Part of the assets of Electromec, a subsidiary of Electronic Specialty Co., has been acquired by Federal. Wolcott, who help found the former Technomatic Co. of California, has also been connected with Northrop Aircraft Co. and Delta Engineering.

► A thorough reorganization of Tork Clock Co., Inc., has resulted in a realigned engineering staff, a larger board of directors, greater capitalization, and last but not least, a change in the company's name. Chief engineer of the "new" Tork Time Controls, Inc., is **John H. Beier**, formerly with Farrand Optical Co. and Norden-Ketay Co. The board now consists of **Cyril J. White** and **Dorset J. White**, president, and vice-president and director of sales, respectively, of TTC; **Arthur A. Berard**, president of Ward-Leonard Electric Co.; **Frank H. Foley**, member of the legal firm of Morgan, Bragg, & Persons and **Fred E. Goldman**, first vice-president of the County Trust Co. of Westchester, N. Y.

► **Edward Foodin**, who has been with Consolidated Avionics Corp. since its inception as a designer of flight instrumentation and data reduction systems, has been named chief engineer. Before joining Avionics, he was with Servomechanisms, Inc., Calif.

► **Marchant Research, Inc.**, the data-processor manufacturing subsidiary of Marchant Calculators, Inc., has appointed **Charles H. Bauer** and **Louis C. Nofrey** division chief engineers responsible for all equipment development projects, and **Bernard T. Wilson** head of the Field Service Div. Bauer has been chief engineer of Telecomputing Corp. Nofrey, formerly

Lest confusion reign

Once there was a Prospect who wanted a small, fast relay that would respond to the direction of flow of current, and which would do it at least a few million times.

He journeyed from Source to Source, asking his questions with straightforward hopefulness. But everywhere the answers were equivocal, with nary a single "Yes" or "No."

There were moments when he *thought* a center off type for differential operation was just what he wanted, but he became uncertain after losing the ability to distinguish between spring bias and the everyday human variety. At other times, also, in the company of other Sources, his hopes rose when answers about "speed" began "will handle 750 pulses per second..." (here was the way *he* liked to hear people talk), only to sink again when followed by such words as "... depending, of course, on the amount of excitation expressed as a net pulse level." Long before, he had abandoned Pinning Down, and had begun a desperate attempt at Keeping Up. But finally he realized he sought in vain; a relay to meet his requirements could not possibly be described simply. He wandered away, head bowed — crumpled fragments of data sheets fluttering after him.

Series 72 HIGH SPEED RELAY

With what may seem like undue pride, we only wish this wretched soul had stumbled on one of our devices, namely the Sigma 72 relay. Not that the language of our literature is so pristine, wholly untouched by the jargon of the Trade, but we could have told him that our 72

is an SPDT relay which responds to direction of current flow.

In correctly designed circuits, takes about 0.2 milliseconds for transferring its contacts and is intended for high speed switching up to 500 pulses per second.

Gives practical value to its high operating speed by switching a 60 ma. 110VDC inductive load half a billion times on the average without maintenance.

Allows repair and adjustment by the user (detailed manual and test set available).

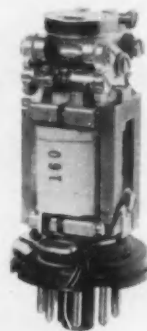
By comparison, takes up little space (1 7/16" dia. x 2 5/8" high) and is lightweight.

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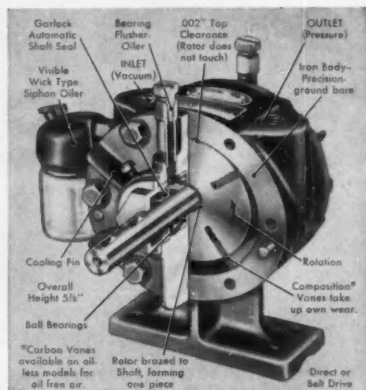
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WHAT'S NEW

with the Livermore Radiation Laboratory of the University of California, is chairman of the Professional Group on Electronic Computers of the IRE's San Francisco chapter. Wilson headed the National Cash Register Co.'s Electronics Div. before coming to Marchant.

►Recent changes at Mason-Neilan Div. of Worthington Corp. spotlight Eric Bianchi, named vice-president for engineering; Paul Wing Jr., chief engineer; F. Kenneth Morrison, president; and Carl Gram, V-P for sales.

►Top-level changes at General Precision Laboratory, Inc., involve the following: Raymond L. Gaman, formerly vice-president, elected executive vice-president and technical director; James W. Murray, another former V-P, elevated to executive vice-president and general manager; Richard W. Lee, formerly director of the Avionic Engineering Div., and William J. Tull, formerly director of the Avionic Sales Div., named vice-presidents; William P. Hilliard, formerly vice-president of Pleasantville Instrument Corp., GPL's manufacturing subsidiary, elected president of PIC, and Raymond G. Johnson, controller, named to the additional office of assistant treasurer. Garman, with GPL since 1945, will be in charge of technical administration, while Murray, who joined in 1951, will head manufacturing. Garman, Murray, and Lee have all had previous experience with MIT's Radiation Laboratory, Garman's work there bringing him a Presidential Certificate of Merit during the last war. His and Murray's posts are newly-created.

►Taking over the Telemetering Dept. of Lockheed Aircraft Corp.'s Missile System Div. is Richard J. Burke, formerly deputy chief of the Underwater Ordnance Dept. of the Naval Ordnance Laboratory, where he worked on the Mark 18 naval mine and headed several divisions. His name is well known in magnetics and instrumentation.

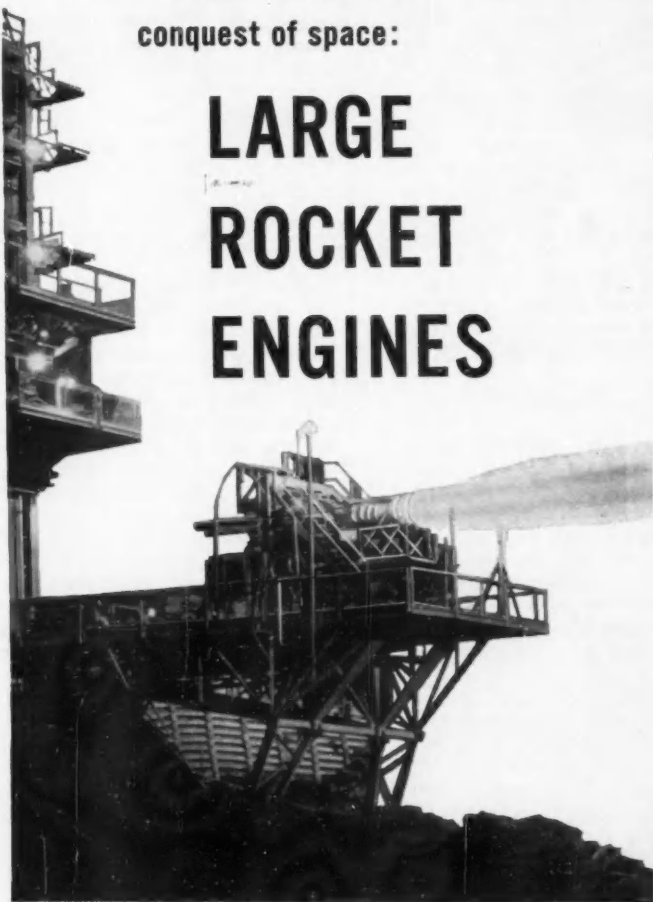
►Fernand H. Matile, factory manager of Lear S. A., subsidiary of Lear, Inc., in Geneva, Switzerland, has been named assistant general manager there. He has also been with Brown Boveri Co. and the Tarex Co. He is a specialist in thermodynamics.

►Another "thermodynamicist", Charles R. St. Clair Jr., has joined the Research & Advanced Development Div. Avco Mfg. Corp. as a senior scientist. He will head the thermodynamics group in the Applied Research Dept.

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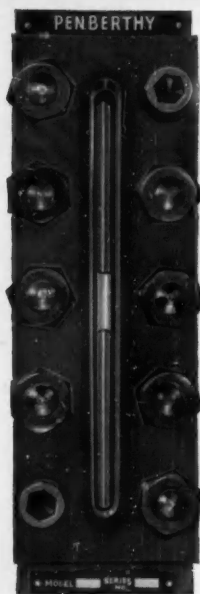
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ABSTRACTS

Records Strain Digitally

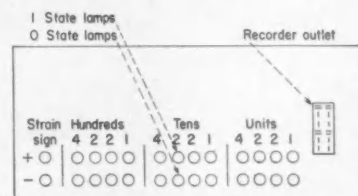
From "A Nine's Complement Decade Counter with Recorder" by J. A. Phillips, Australian Defense Scientific Service. "Electronic Engineering" (British) August 1956.

The author describes equipment designed primarily to display, in binary decimal form, positive and negative strains. "The actual number representing strain was wholly positive, being a series of pulses passed by an electronic gate . . . In the counter being considered here it was required that a mechanical strain, measured and recorded as a count of pulses . . . should be represented by positive or negative numbers analogous to the strain itself."

A known pulse count (1000) was used as zero strain, and numbers larger than this proportionally as positive strain. However, the nine's complement of a number smaller than 1000 proportionally request negative strain. "Nine's complements of decimal numbers are formed by subtracting each from nine, i. e., the nine's complement of 751 is 248. It will be seen that 248 is, with an error of one, the complement of 10 of 751, i. e., $751 + 249$ is a power of ten . . . if a power of ten is taken to represent zero strain the positive strains will be represented by a number greater than the power of ten used as a base while negative strains will, with an error of one, be represented by the nine's complement of a number less than the base. For example, if 1000 is taken as the base, i. e., zero strain, then a count of 1751 represents a positive strain proportional to 751 while a count of 280 is analogous to a negative strain of $719 + 1 = 720$; for $1000 - 280 = 720$."

The input pulse signals are binary in nature; thus the above technique could have used binary complements if the visual readout had not required a decimal system. Accordingly binary decade counters convert the binary pulses to a group of four on-off lamps for each decade. The "on" values of each lamps are weighted 1, 2, 2*, 4, so that adding the weighted values of the "on" lamps gives the decimal value in that decade. The system requires $3 \times 4 = 12$ binary stage for the three decades, plus another binary stage to indicate either 1 or 0 in the fourth decade to represent either positive or negative numbers.

Electronically, the counter consists of the 13 binary scales in cascade. Neon lamps in each binary scale indicate either a 1 or a 0 for each weighted value. The article contains a complete circuit diagram for one decade of the nine's complement counter, the output of which feeds into the next decade, etc.



The figure shows how the digital strain information is displayed. In each column either the 1 state lamp or the 0 state lamp is on. The row containing the lit strain sign lamp is read. Thus, for negative strain, i. e., a count less than 1000 pulses, the negative strain sign is on, and the lights on in that row indicate, in binary decimal rotation, the proportional strain. However, once the count goes to 1000 or more, the top row is read to obtain the proportional strain. Using the fourth position to indicate the sign effectively subtracts the 1000 zero base count, so that the count visible on the panel directly indicates the proportional strain.

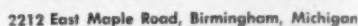
Synchros vs. Pots

From "Important Factors Influencing the Choice Between a Synchro and a Potentiometer as an Angular Position Pickoff" by H. A. Dinter Jr., Minneapolis-Honeywell Regulator Co., AIEE Paper 56-449, "AIEE Transactions—Applications and Industry", September 1956, pp. 198-204.

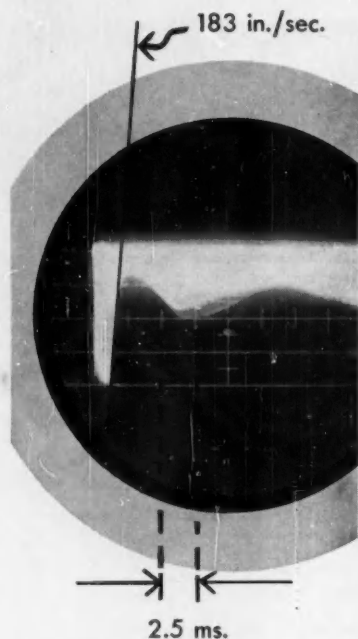
The express purpose of this paper is to stimulate discussion between manufacturer and user by outlining some of the more difficult problems which face the designer of modern precision attitude reference systems such as "stable platforms" and certain automatic astronomical instruments, and by discussing factors which affect his choice between synchros and potentiometers as position pickoffs in these applications.

Probably the most common mistake made in choosing a specific type of pickoff lies in deciding at the outset that a system shall use exclusively synchro pickoffs or potentiometer

The author presents a four-page comparative discussion of synchro and potentiometer characteristics. For the potentiometer, independent linearity, zero-based linearity, and terminal linearity are defined in the normal manner. Then: "A far better figure of merit for potentiometers used as pick-offs may be obtained by converting the percentage linearity figure first to degrees linearity and then to inches along the wiper travel circumference. In this way, the quality of the resistance elements may be compared independently . . . It must, of course, be realized that linearity error stated in inches includes errors caused by lack of uniformity in the wire and mandrel as well as actual misplacement of turns, but linearity in inches does provide a fair and reasonable figure of merit for comparison of potentiometer quality." This statement is rebutted by W. L. Deniston of Fairchild Controls Corp., who feels that this kind of information is more useful to the manufacturer than the user. From the amount of this type of submitted discussion, it appears the author has accomplished his purpose.



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NEW BOOKS

Zeroing in on Servos

FEEDBACK SYSTEMS THEORY AND DESIGN (*Theorie et Technique des Asservissements*), J. C. GILLE, M. PELEGRIN, and P. DECAULNE, Published by Dunod, Paris, 1956.

Practically all the works published on servos deal either with servos in general (as such they apply to all kinds but do not enable the accomplishment of a particular servo project through to its conclusion); or with particular servo problems (then they only help that engineer who has to cope precisely with those problems).

The present authors have succeeded in writing a book which includes everything about servos. They start by posing the problem of servo synthesis as it arises in the field: given some elements of a feedback system, design the remaining elements so that the complete system will meet some given performance requirements.

The bulk of the work is then divided into two parts. The first, on servo theory (linear and nonlinear), emphasizes the problem of performance criteria: how servo performance can be evaluated, how a given performance can be met, and what conditions this performance imposes on the different component parts. The second part is devoted to servo component parts, which are studied from the synthesis viewpoint, and answers the questions: which of their characteristics are important for the overall performance and how should their choice be guided, always having in mind the problem of overall performance? This overall performance is the constant basis for reference in the second part.

So the general theory and the components design problem are closely united in this book: it is very probably the first absolutely synthetic work to treat the servo synthesis problem from its beginning through to its conclusion.

The first chapter introduces the concept of feedback system (follow-up or regulator) with examples which range from autopilots to the chain of command in the army. It develops a clear, realistic discussion of the specific properties of feedback systems as compared to open-loop systems with indication of their possibilities and limits (such discussion has been neglected up to now by engineers on the one hand and overemphasized by journalists and pseudo-philosophers on the other).

The linear servo theory (classical and statistical) is then laid out, great importance being given to linear system dynamics in general, with linear servo theory treated as a particular case. Transfer-matrices and the problem of impedance matching also receive thorough attention, as do: the assumptions involved by the concept of linearity; those concepts of the Bodlaw and Shannon information theories which can be of practical use to servo engineers; and performance criteria (statistical and nonstatistical). Other features of this chapter: reduction of all the curves and diagrams used to the same scale, and an exposition of a general theory of multiple loop servomechanisms, with emphasis on analog computers and simulators.

The linear theory is followed by three chapters on nonlinear theory. After a discussion of those nonlinearities most frequently encountered in servos, some classical cases (Van der Pol equations, etc.) are treated. Two methods of analysis and synthesis are dealt with in detail: the Dutilh-Kochenburger first harmonic approximation and the Poincare method in the phase-plane. For the latter, both graphical and analytical approaches are used; a thorough application is made to many types of servos and to the problem of optimization.

In the second part of the book, on servo components, sensing devices, amplifiers, and motors are examined from the viewpoint of overall performance. Three chapters devoted to servo motors emphasize the problem of the motor choice for a given feedback system. A new method is presented which enables the requirements to be met more closely than the methods generally used up to now. Complete numerical data sheets are given for the existing French commercial units (electric and hydraulic).

In the last chapter the authors present a few directing principles for servo design, which are most important in practice. Two examples of servo projects (a position servo and a missile autopilot) are conducted through to the determination of the numerical values.

One more thing impressed me as I read the book: the ability of the authors (who developed the most elaborate servo-teaching which exists in France at the present time) to be perfectly clear and progressive.

In fact, this advanced work can be read and studied by anyone who knows what a differential equation

and what a complex exponential are (the residue theorem is not a prerequisite). All the notions introduced, such as correlation functions, limit cycles, singular points, etc., are explained physically before they are defined mathematically and are all illustrated by various examples.

F. H. Raymond
Seine, France

Ferretting Frequencies

SPECTROSCOPY AT RADIO AND MICROWAVE FREQUENCIES. D. J. E. Ingram. 332 pp. Published by Philosophical Library, Inc., New York. \$15.

Engineers and scientists planning to undertake projects in radio-frequency and microwave spectroscopy will find this book of great value, particularly if their field is electron paramagnetic resonance, the author's specialty. At the same time the overall subject of spectroscopy is treated broadly enough to hold the attention of the general-information seeker. Wherever possible, the use of quantum mechanics and mathematical detail is avoided.

Going on the assumption that the average reader has little or no knowledge of microwave techniques, Ingram follows up a short introduction with an excellent three-chapter summary of production and detection of microwaves, wave guide techniques, and microwave spectrometers. The description of the microwave apparatus is considerably detailed, although recent devices such as ferrite gyrators and circulators are not discussed. These initial chapters contain practical circuit diagrams of the electronic equipment used in both microwave and radio-frequency apparatus.

Discussion of gaseous spectroscopy, paramagnetic resonance, ferromagnetic resonance, free radicals, F-centers, molecular beams, and nuclear resonance, follow description of the apparatus. The treatment of molecular beams and nuclear resonance are necessarily somewhat sketchy, although the excellent bibliographies at the end of each chapter give a good coverage of the literature in these fields.

The final chapter, outlining the applications of microwave and r-f spectroscopy, will perhaps be of greatest interest to the general reader. Here Ingram reviews the practical as well as the analytical applications, im-

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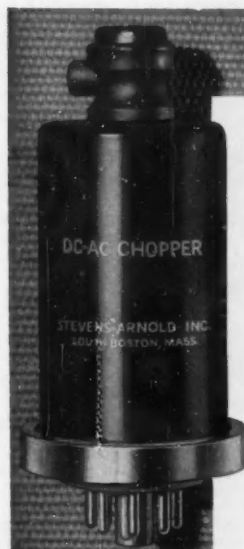
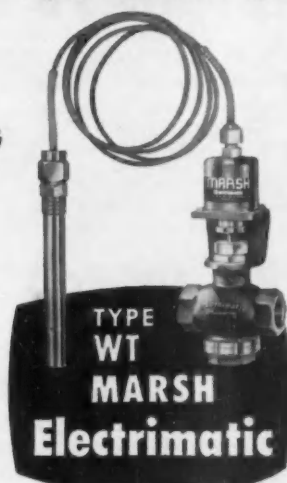
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Young Mathematician Replies*

RANDOM PROCESSES IN AUTOMATIC CONTROL. J. H. Laning, Jr. and R. H. Battin. 429 pp. Published by McGraw-Hill Book Company, Inc., New York. \$10.00

This is an exposition of the theory of random processes, with applications to the analysis of errors in automatic control systems. The authors are directors of the Instrumentation Laboratory at MIT. The random process theory leads to a system design which is optimum (in some prescribed sense) in the face of conflicting objectives of speed and accuracy of response on the one hand, and adequate discrimination against random disturbances of input data and component behavior on the other.

The book is a welcome contribution and is highly recommended for advanced students and practicing engineers. The authors are careful and thorough in their treatment, giving precise definitions of the concepts introduced. Valuable features of the book are the motivating discussions which precede mathematical theory and the numerous examples which follow and illustrate the theory. There are 102 figures and 95 worked examples, an average for each category of about one every four pages. This is probably generous enough to dispel the trepidations of some who may be concerned about the degree of abstractness of the presentation. Another point is that the examples and problems are anything but academic or trivial. The authors have formulated many illustrations from extensive experience gained in attacking practical and often difficult problems, particularly those born of military considerations.

Chapter 1 contains a concise description of the optimum design problem with emphasis on the specification of some readily-calculated cri-

*See Feedback, Nov. 1956, page 10.

terion of performance (such as the minimum mean-squared error or the maximum signal-to-noise ratio or probability of a particular event). Chapter 2, on probability theory, is the longest (81 pages), but can be put aside as a convenient reference source by those already familiar with these concepts. The treatment is based upon the modern notion of sets and set functions but the basic concepts are accompanied by motivating discussions and examples. The lack of graphs of the principal density functions is, however, regrettable.

Chapter 3 gives an analytic description of random processes in terms of the moments of the first and second probability functions. A distinction is made between energy and power spectral densities. The relation between the autocorrelation function and the power spectral density is established but, curiously, the common appellation "Wiener-Khinchine" is never mentioned. Chapter 4 develops the theory of the shot effect and the Gaussian random process, following the general procedure of S. O. Rice. This includes an analysis of the response of certain nonlinear devices to such noise.

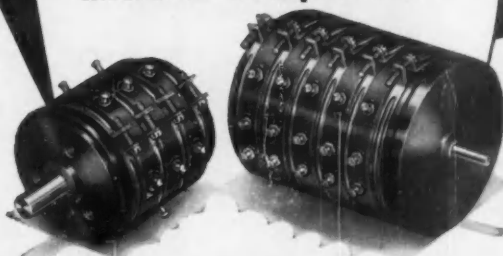
Chapter 5 is concerned with the "classical" problem of analyzing the response of a linear, time-invariant system to stationary random inputs. Included are smoothing and prediction operations, the Phillips method of mean-squared error minimization, and an interesting section on analog techniques for obtaining correlation functions. The inverse problem (Wiener theory) of synthesizing an optimum linear system subject to stationary random inputs is formulated and solved in several different ways in Chapter 7.

Chapter 6 describes some methods of calculating mean-squared errors in nonstationary processes. Time-varying linear systems as well as systems with nonstationary inputs are considered, but results in this relatively new field are still meager. Solutions are indicated mainly through application of an analog computation techniques. An elegant and clearly written description of analog methods is contained in an appendix. The useful method of adjoint systems and its applications are fully discussed, including a mathematical proof. The chapter closes with a novel application of the method of steepest descents.

Chapter 8 on operations with finite data represents an attempt to broaden

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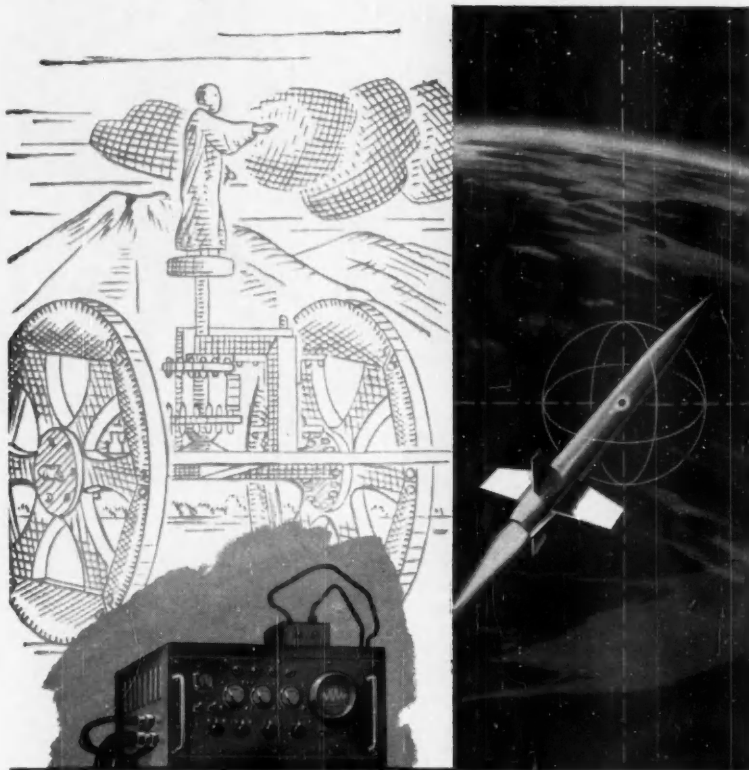
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the Wiener optimum filter theory by relaxing some of the assumptions. The restriction to linear, lumped-parameter devices is in general abandoned and, even more practically, operations on only a finite past history of signal and noise are considered. The results obtained are theoretical and largely original and serve to point out the limitations of system performance caused by the inherent properties of the input data itself.

A bibliography and index are provided, although the latter is almost shamefully inadequate in view of the otherwise generally high standards of editing and typography. The number of errors is remarkably few, but an obvious omission occurs in equation 4.3-10 (page 162).

Myron Kantor
Los Angeles, Calif.

Industrial Motor Control

ELECTRIC MOTORS AND CONTROLS.
Edited and published by British Electrical Development Association,
2 Savoy-Hill, London, W.C. 2.
England. 8 shillings, 6 pence.

This book covers ac and dc motors, and means commonly used in industry for controlling them. The particular advantages of modern automatic control are interestingly brought out through description of how a steel strip mill benefited by a change from hydraulic to electric drive and control. Clearly-written and well-illustrated, the little book will be of value to anyone concerned with modern motor drive and control, especially the engineer with limited formal training and the technical assistant learning by self-study.

Payroll Computing

WAGE ACCOUNTING BY ELECTRONIC COMPUTER. Published by H. M. Stationery Office, York House, Kingsway, London, W.C. 2, England. 2 shillings, 9.5 pence (postage included).

This report is the first by a team studying procedures for doing clerical work on automatic electronic digital computers. The project was carried out at the National Physical Laboratory at Teddington under the joint sponsorship of this laboratory. An investigation of the broad aspects of large-scale payroll calculation is described and the results proved out in a

detailed examination of a particular case. This latter shows that:

- base pay, overtime, income tax, insurance deductions, and various special allocations can be easily scheduled for computation

- this can be effected expeditiously on existing high-speed computers

- considerable reduction in large-sized payroll staffs and increased efficiency of those remaining simultaneously result

The team's report is easy reading for accountants, business managers, computer engineers, and others interested in application of high-speed computers for office work. Those interested will find that the details of the particular example and the various other specific data presented nicely buttress and complement the general arguments of texts such as R. H. Brown's *Office Automation* (CtE, April '56, pp. 167-168) and H. S. Levin's *Office Work and Automation*, John Wiley & Sons, Inc., New York, 1956, 203 pp.

German Control Practices

REGELUNGSTECHNIK (*Control Engineering: Fundamentals of Control Technique and Applications in Practice*). 288 pp. Edited and published by *Allgemeine Elektrizitäts-Gesellschaft*, Kenbrunnenstrasse 107a, Berlin N. 31, Germany. Price (on application).

The great German electrical combine commonly designated by the initials AEG has long been in the forefront of European firms active in control engineering. Since it brought out the famous Tirill-type voltage regulators a half-century ago, a steady stream of contributions has poured from its research and development laboratories. This long and fruitful activity, the numerous applications of automatic control pioneered by its engineers, and the rapid growth in scope and industrial importance that control engineering itself has experienced in the last decade have prompted publication of the book under review.

Its prime purpose is "not only to describe the apparatus used and its technical applications, but to present the basic concepts of control engineering. For the multiplicity of applications of control, which are ever increasing with the extended use of automatic control, makes a uniform treatment of all such problems a com-

PELLING necessity." To achieve these ends, practice rather than theory, graphics and illustration rather than equations, fill the pages. Illustrating the many-sidedness of control engineering are the numerous short articles by different authors—rather than a few long chapters by only several writers. For unity of presentation, all symbolism, terminology, and definitions are codified with the recent German Standard DIN 19226.

The 36 articles, each written by an AEG specialist, are grouped under four main headings. The six papers in the first group, "Fundamentals of Control Problems", cover characteristic features of automatic control systems; the fundamental principles of control engineering; symbolism, terminology, and definitions of automatic control engineering; representation of components and systems by block diagrams; graphical representation of characteristics of systems and use of transfer functions; and all of these aspects as they arise in a particular application: proportional control of temperature.

The second group, "Control Problems in Power Generation and Distribution", contains 13 articles ranging from "Transducer-controlled charging of storage batteries" and "Control of rectifiers by means of magnetic and electronic amplifiers" to "Voltage and frequency stabilization of motor-generators by electronic control" and "The AEG resonance controller for automatic adjustment of Petersen coils". The third group of 12 articles, on "The Control of Industrial Drives" covers topics as diverse as "The automatically-controlled Ward-Leonard drive", "Register control (of paper machines)", and "Drives for stocking-knitting machines".

The five items in the fourth group, "Problems in Process Control", encompass applications of magnetic amplifiers, automatic control of the speed of a self-excited mechanical vibrator, automatic control of the vacuum of an air-cooled steam condenser, automatic control of steam turbines, and application of the swing-coil regulator in process control.

An English translation of the book—the recent 219-page "Special Issue—Control and Regulation" of AEG PROGRESS (the English language house-organ of the AEG)—has been prepared with careful attention to British Standards No. 1523.

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WHAT'S AHEAD: MEETINGS

JANUARY

American Institute of Electrical Engineers and Institute of Radio Engineers, Symposium on Reliability and Quality Control, Hotel Statler, Washington, D. C. Jan. 14-15

American Institute of Electrical Engineers, Winter General Meeting, Hotel Statler, New York Jan. 21-25

FEBRUARY

Instrument Society of America, New York Section, Midwinter Conference (Aircraft Instrumentation), Garden City Hotel, Garden City, Long Island, N. Y. Feb. 7

Institute of Radio Engineers, Transistor and Solid State Conference, University of Pennsylvania and Bellevue-Stratford Hotel, Philadelphia, Pa. Feb. 14-15

Western Joint Computer Conference, Hotel Statler, Los Angeles Feb. 26-28

MARCH

American Society of Mechanical Engineers, Nuclear Congress, Convention Hall, Philadelphia March 10-16

Institute of Radio Engineers, 1957 National Convention and Exhibition, N. Y. Coliseum and Hotel Waldorf-Astoria, New York March 18-21

Nineteenth Annual American Power Conference, Hotel Sherman, Chicago March 27-29

APRIL

Instrument Society of America, National Nuclear Instrumentation Conference, and Third South-eastern Regional Exhibit, Atlanta Biltmore Hotel, Atlanta, Ga. April 10-12

Second National Simulation Conference, and Ninth Southwestern Institute of Radio Engineers Conference and Electronics Show, Shamrock Hotel, Houston, Texas April 11-13

American Society of Mechanical Engineers, Instruments & Regulators Div. (IRD) Third Annual Conference, Northwestern University, Evanston, Ill. April 22-24

Second National Industrial Research Conference, "Research for Profit", sponsored by Armour Research Foundation of Illinois Institute of Technology, Conrad Hilton Hotel, Chicago April 24-25

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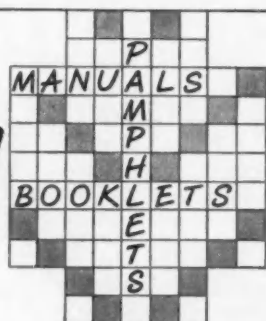
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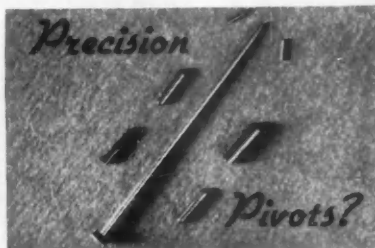
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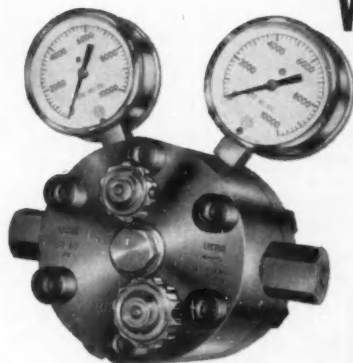
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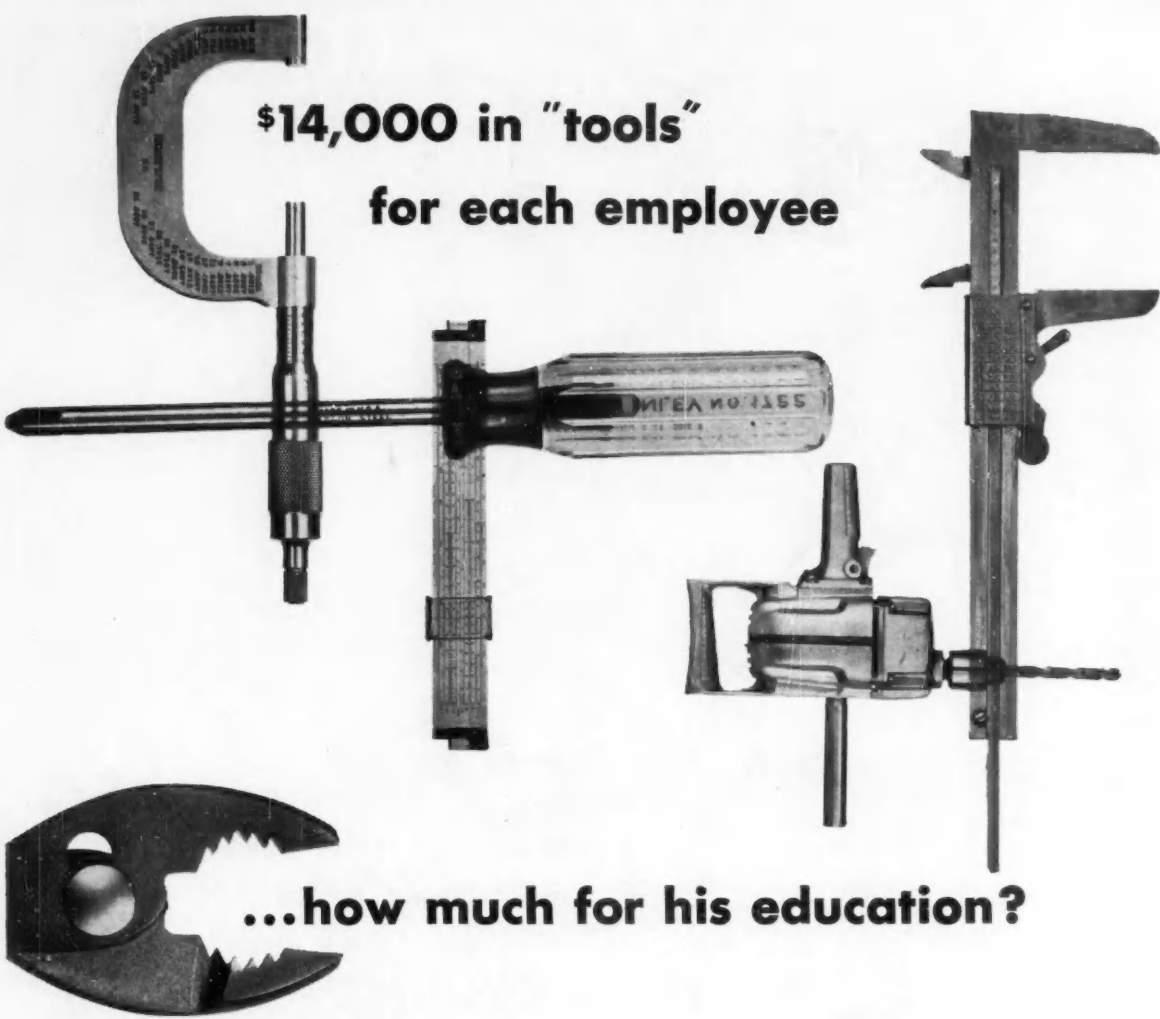
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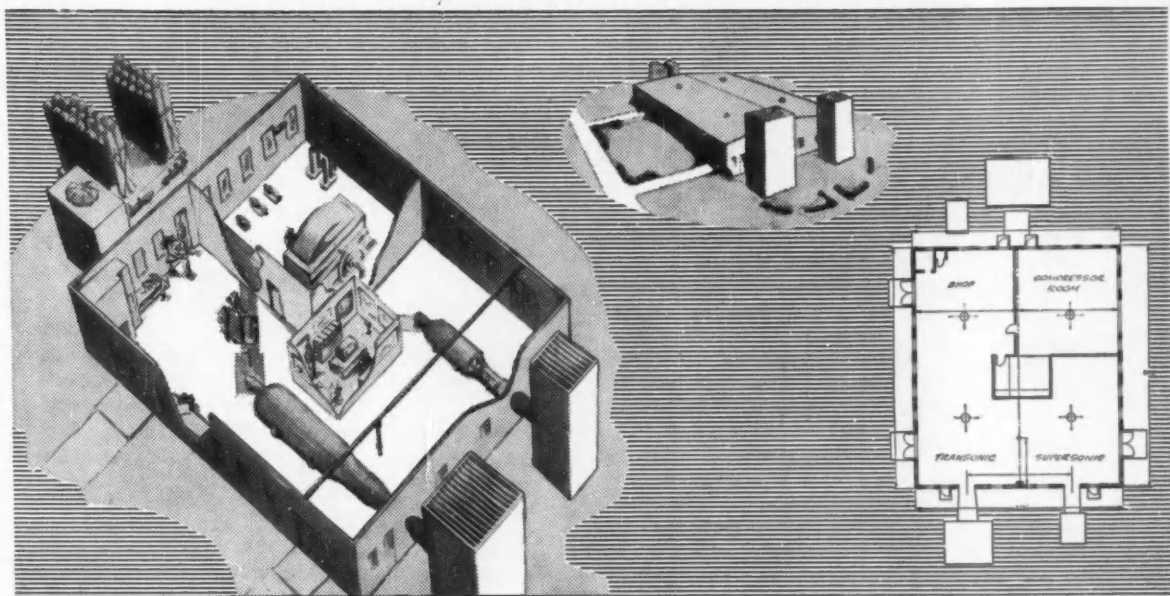
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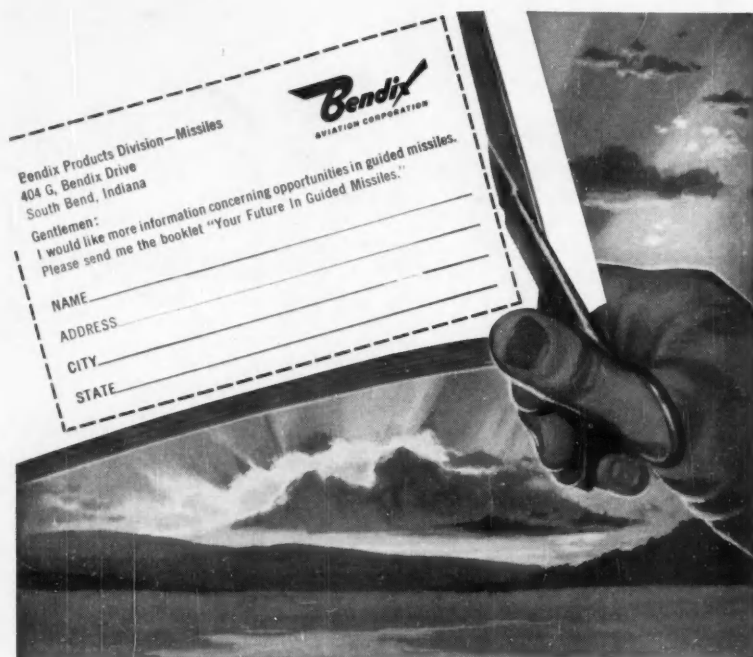
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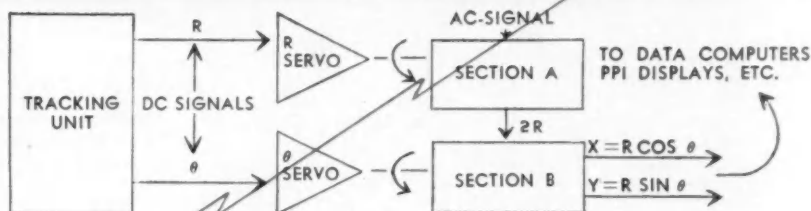
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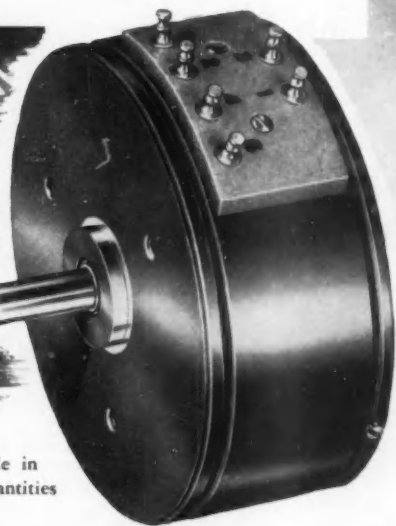
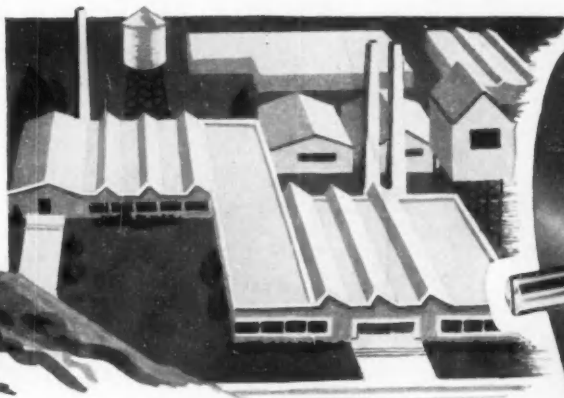
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$$X = R \cos \theta \quad Y = R \sin \theta$$



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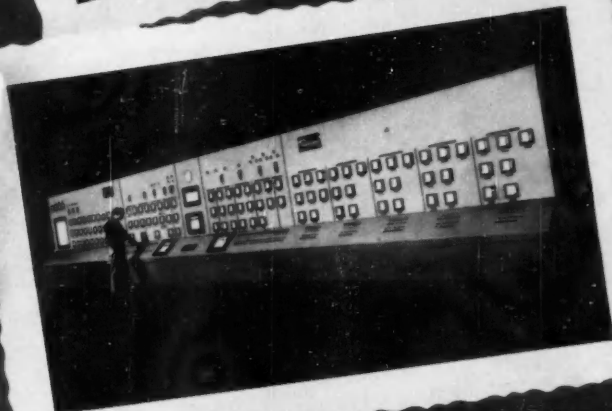
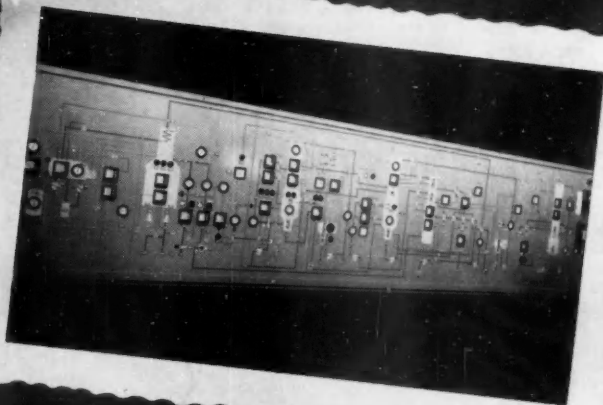
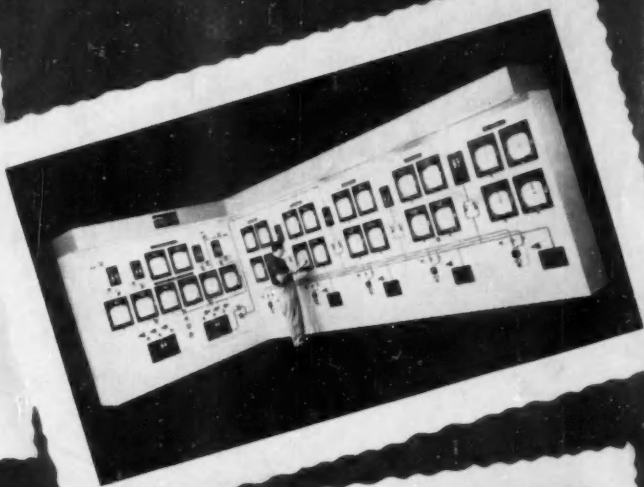
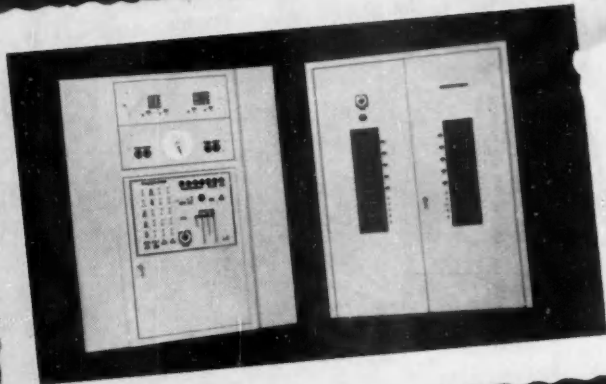
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